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EVALUATION OF THE CPO AUXILIARY PROCESSOR

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ABSTRACT

Under Contract AF 33(657)-14648, both routine operation of the Cumberland Plateau Seismological Observatory and considerable applied research were conducted. During the last project year, on-line real-time detection and identification processing using the CPO Auxiliary Processor was implemented and evaluated at CPO for the purpose of studying automatic detection processing. The CPO Auxiliary Processor computes two classes of detection outputs, the Fisher analysis-of-variance statistic and the Wiener power statistic, and one class of identification output, the United Kingdom technique. These detection outputs were compared on-line against a fixed signal threshold level, providing a continuous real-time "yes-no" output for signal. However, the fixed-threshold detection levels were initially difficult to determine accurately and, once determined, it was found that they were highly non-time stationary. Adaptive threshold detectors incorporated into the Auxiliary Processor could overcome the non-time stationarity of the threshold detectors. Off-line applied research was performed to support the on-line research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

In addition to routine operation of the Cumberland Plateau Seismological Observatory, considerable applied research has been conducted under Contract AF33(657)-14648 to advance the understanding of array processing technology applicable to small seismic arrays used in the nuclear detection and classification problem. During the last project year, under VT/6704 on-line real-time detection and identification processing was implemented and evaluated at CPO for the primary purpose of studying automatic detection processing.

On-line processing was implemented using the CPO Auxiliary Processor (Figure I-1) which computes two classes of detection outputs, the Fisher analysis-of-variance statistic and the Wiener power statistic, and one class of identification output, the United Kingdom technique. The detection outputs were compared on-line against a fixed signal threshold level for automatic detection. From this comparison a continuous real-time "yes-no" output was provided for signal. This output, along with the detection and identification data, was recorded on Develocorder film.

Contained in this report is a brief description of the digital processing hardware and results of the hardware evaluation. Conclusions, as well as supporting data regarding the evaluation of on-line detection and identification processing, are presented. Also, results from off-line supporting applied research are covered.

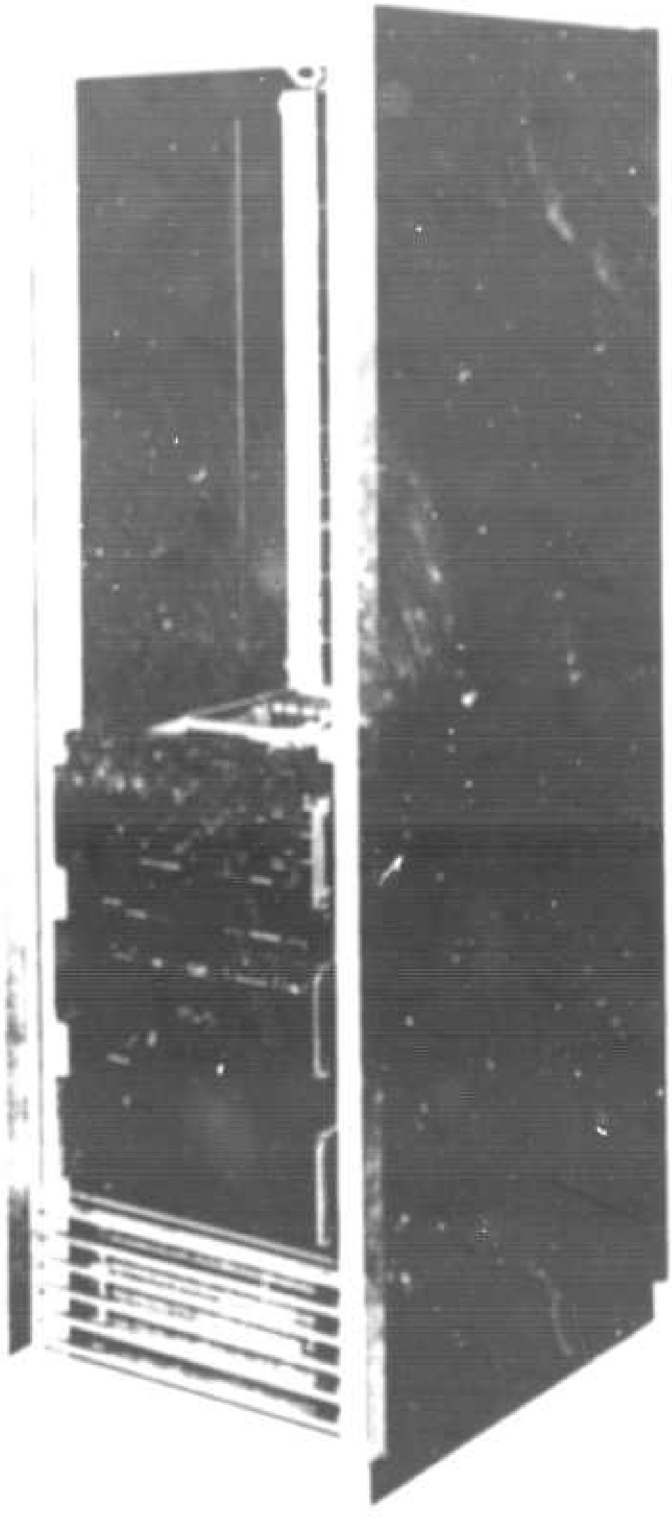

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Figure 1-1. Auxiliary Processor

SECTION II

SUMMARY AND CONCLUSIONS

On-line real-time identification and automatic detection processing began at CPO in December 1966 with the installation and operation of the Auxiliary Processor. This unit interfaces with the CPO MCF processor from which it derives all input signal data. The Auxiliary Processor computes two United Kingdom outputs, one Fisher analysis-of-variance detection output and four Wiener power detection outputs. A "yes-no" decision for signal is presented in real-time based upon the threshold level detection output comparison. All data is displayed on Develocorder film.

The primary reason for implementing the Auxiliary Processor was to evaluate the feasibility and effectiveness of automatic detection processing as applied to the P-wave detection problem for small diameter short-period seismic arrays. Comparison of Fisher statistic and Wiener power detection processing over large quantities of data, as well as some classification work using the UK processed data, was planned.

After the Auxiliary Processor design, construction and installation phase from May 1966 through December 1966, a performance and hardware evaluation phase was conducted to answer questions regarding feasibility, reliability, and effectiveness. Concurrent with this work, off-line applied research directed toward extending the present processing technology and understanding was performed in Dallas.

A. HARDWARE EVALUATION

Results of the hardware evaluation indicate that the system is highly reliable. Not one component failure occurred during the 30 December 1966 to 10 April 1967 operating period. The initial setup and programing of the system is difficult and requires the empirical determination of many parameters which must be manually programed. This difficulty is particularly true of the Fisher process since knowledge of the Fisher intermediate term values K1, K2 and K3 must be known in order to determine the optimum data truncate settings. Several recommendations for modifications of possible future systems are presented in Section III.

B. ON-LINE PROCESSING EVALUATION

1. Detection Processing

Evaluation of the Auxiliary Processor as a detection device indicated considerable difficulty exists with the fixed-threshold detection levels for the Fisher and Wiener outputs. Initially it was difficult to determine accurately the desired threshold level. Once the levels were determined, it was found that they were highly non-time stationary which meant that the false-alarm rate could not be fixed. Attempts to adopt standard procedures to update the threshold levels on a daily (and sometimes more often) basis proved to be inadequate. The variations in threshold level were significant enough that the automatic detection outputs were for practical purposes useless.

Adaptive threshold detectors should be incorporated in the Auxiliary Processor. An adaption algorithm is presented in the appendix which is suitable for incorporation into the existing system. It is felt that the Auxiliary Processor can be a significant tool in the automatic P-wave detection problem with this addition.

2. Identification Processing

The two UK outputs were properly implemented in the Auxiliary Processor but are of limited use at CPO for classification. First, this type of computation is designed for use on a large diameter crossarray (20 km has been used). The CPO array, which is 3.6 km in diameter, lacks sufficient directional resolution and violates the assumption that noise is uncorrelated across the array. Second, the two outputs may be programed for only two directions, severely limiting the class of signals which may be studied. Third, classification work requires the preservation of signal waveform for all events. This causes a basic dynamic range conflict with the MCF which is a detection device requiring adequate noise for coherent noise suppression. The MCF Auxiliary Processor system is limited to a 12-bit (66-db) dynamic range on input. Since on-line emphasis was placed on MCF signal extraction and detection processing, the class of signals available for study was highly restricted. Large signals of interest were clipped on input or during intermediate computations and small signals of interest (e.g., NTS shots) were not detected on the Develocorder display. An adequate library of events for study was not collected because of these limitations.

Work in this area was subsequently shifted to the MCF and Auxiliary Processor evaluation. The identification processing technique warrants study if the processor is installed at a more suitable array location and sufficient events can be accumulated.

C. OFF-LINE APPLIED RESEARCH

Off-line Dallas-based supporting research was directed primarily toward determining parameter specifications for the Auxiliary Processor program and toward investigating properties of the Fisher output. Two critical parameters, the integration gate length for the detection outputs and the low-cut frequency filter specification necessary for prefiltering the Fisher input data, were determined from studies of CPO signal properties. Effect of correlated noise on the Fisher output was studied empirically in relation to the low-cut filter specification. Compared to the Wiener outputs, signal attenuation for the Fisher computation as a function of wavenumber was determined to be significantly greater.

The variable threshold problem for a fixed false-alarm rate was investigated and found to be related to the RMS input noise level for the Fisher output. This increase could not be related to the effect of a particular noise contributor, but it is reasonable to assume that there may be a strong correlation to the mantle P-wave noise level.

D. CONCLUSIONS

Much useful information for advancing the state-of-the-art real-time automatic detection processing was gained by the implementation and evaluation of the CPO Auxiliary Processor. Both the Wiener power and Fisher statistic computations appear to be useful for detection purposes, but completely automatic detection should be accomplished with an adaptive threshold device. Such a device can be easily incorporated into the existing hardware with a relatively minor modification.

Little information was gained from computation of the UK technique on-line at CPO. The adverse array properties and dynamic range problem coupled with the sparseness of desired events severely limited the necessary library of events required for this study.

Off-line Dallas supported research complimented the on-line evaluation and provided a more comprehensive understanding of on-line Fisher and Wiener automatic detection processing.

SECTION III

PROCESSOR IMPLEMENTATION AND EVALUATION

The purpose of this section is to provide a concise description of the CPO Auxiliary Processor, present results of the hardware evaluation conducted during the on-line operating period and recommend system modifications based upon experience gained through system operation.

A. SYSTEM DESCRIPTION

A detailed system description may be found in the Instruction Manual, Operation and Maintenance Auxiliary Processor[1] and the Specification for Auxiliary Processor Modification, Advanced Multi-Channel Filter.[2]

1. Description of the Key System Operations

a. Fisher Process

The Fisher process is a statistical signal detection process which operates on the filtered outputs of each MCF input channel. Filtered outputs are formed by the MCF in the beam-steer process using the following equation.

$$B_n^k = \sum_{i=0}^{I} S_{n-i}^k \; a_i^k \tag{1}$$

where

S_n^k is the value of the most recent sample of the data for input channel k (where k ranges from 0 to k)

a_o^k through a_i^k are constants

$I+1$ is the number of filter points

By using the CPO MCF, the auxiliary processor computes a Fisher output according to the following equation.

$$\text{Fisher Output} = \frac{N1\left(K3 - \frac{K1}{P}\right)}{\left(K3 - \frac{K1}{P}\right) + N2\left(K2 - \frac{K3}{K+1}\right)} \tag{2}$$

where

N_1 and N_2	are normalization constants
$K + 1$	is the number of input channels
P	is the Fisher history length

K1, K2, and K3 are the intermediate Fisher terms which are formed using the following equations.

$$K1 = \left(\sum_{p=1}^{P} \sum_{k=0}^{K} B^{k}_{n-(p-1)} \right)^2 \qquad (3)$$

$$K2 = \sum_{p=1}^{P} \sum_{k=0}^{K} \left(B^{k}_{n-(p-1)} \right)^2 \qquad (4)$$

$$K3 = \sum_{p=1}^{P} \left(\sum_{k=0}^{K} B^{k}_{n-(p-1)} \right)^2 \qquad (5)$$

The Fisher output computed by the processor is a transform of the true Fisher process which is given by

$$F = \frac{K3 - \frac{K1}{P}}{K2 - \frac{K3}{K+1}} \qquad (6)$$

Under highly coherent signal conditions, the denominator of F is 0, an undefined state for the hardware as implemented. To avoid this condition, F is transformed as follows:

$$\text{Fisher Output} = \frac{A \cdot F + B}{C \cdot F + D} = \frac{(A/C)\,F}{F + D/C} \tag{7}$$

where

$$B = 0$$
$$A/C = N1$$
$$D/C = M2$$

The effect of this transform as a function of N2 is illustrated in Figure III-1. N1 sets the maximum value (routinely 777_8 or 512_{10}, the largest possible output number as a result of the 9-bit output register). Selection of N2 is based on the F-value, computed for the site ambient-noise field (at CPO, $F \simeq 2.2$). This may be determined operationally by finding one or two processor-average, ambient-noise output values over a predetermined gate by using the Fisher threshold detectors and by reading the F value for the known N2.

b. United Kingdom Process

The United Kingdom process performs the 0-lag crosscorrelation of two beam-steer outputs. The auxiliary processor forms two such outputs using the following equation.

$$\text{UK Output} = \sum_{p=1}^{P} C^{j}_{n-(p-1)} \; C^{k}_{n-(p-1)} \tag{8}$$

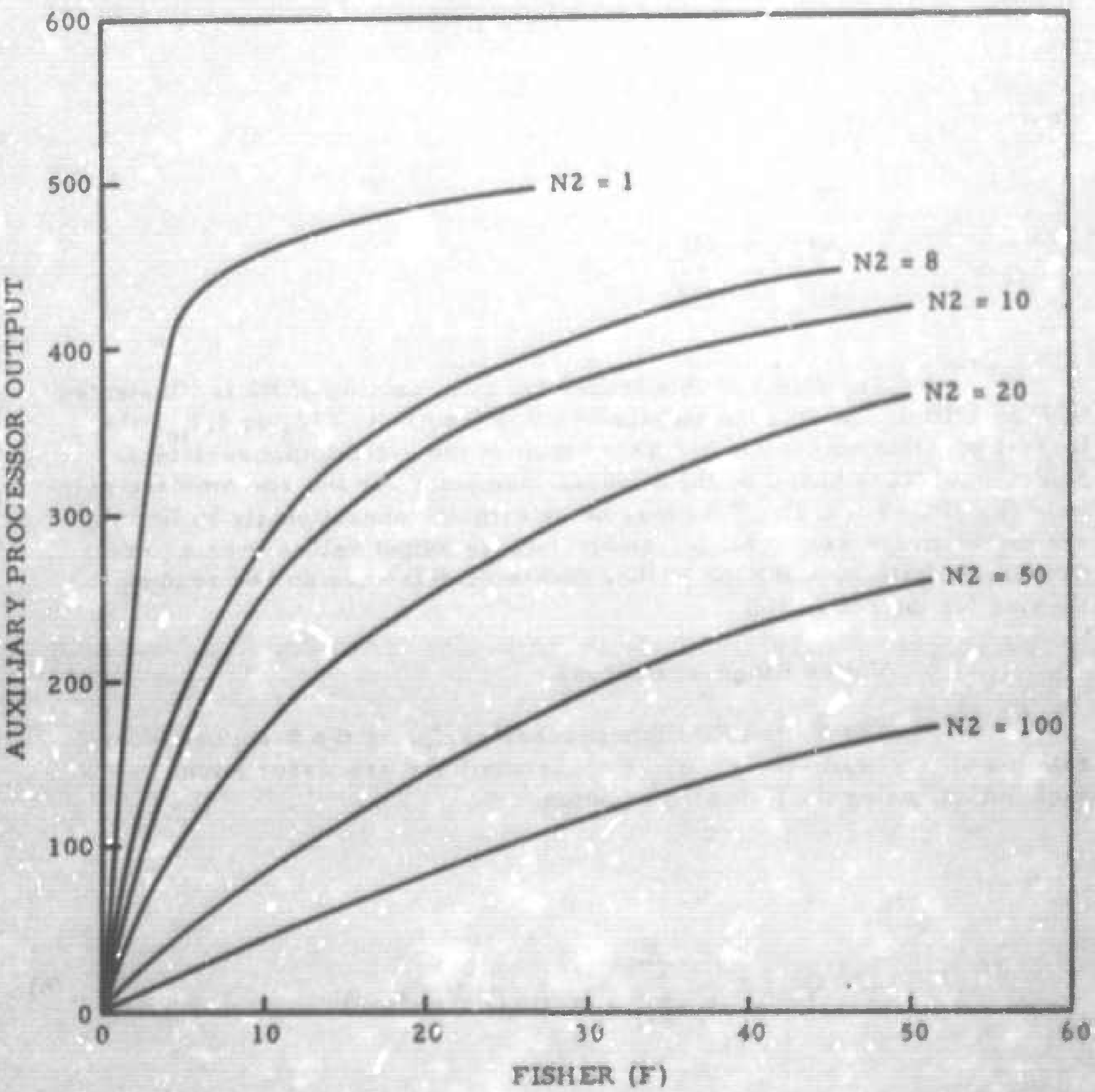

Figure III-1. Fisher Transformation as a Function of N2

where

$C^{j}_{n-(p-1)}$ = j^{th} beam-steer output of the MCF processor

$C^{k}_{n-(p-1)}$ = k^{th} beam-steer output of the MCF processor

$j \neq k$

P = number of UK history points

n = most recent beam-steer output

n-1 = next most recent beam-steer output, etc.

A second UK output is generated using outputs l and m, where $l \neq m$ and j, k, l, and m are not equal.

New UK outputs are computed every 50 msec.

c. Wiener Power Process

The auxiliary processor forms four Wiener power outputs using the following equation.

$$\text{Output} = \sum_{r=1}^{R} \sum_{s=1}^{S} \left(A_m\right)^2 \tag{9}$$

where

$m = n(s-1) - (r-1)S$

A_m = the MCF output at time m, truncated to 11 bits plus sign

A_n = the most recent MCF output (A_{n-1} is the next most recent MCF output, etc.)

$$S = \frac{\text{sample interval}}{\text{frame time}} = \frac{\text{sample interval}}{\text{50 msec}}$$

$$r = \frac{\text{window width in sec}}{\text{sample interval}}$$

The multichannel power processor output is an R x S x 50-msec window of an S x 50-msec sample interval of an MCF output.

d. Threshold Detectors

Digital threshold detectors are provided in the Auxiliary Processor for the Fisher output and the four power outputs. The threshold detectors provide a separate signal output when a monitored output equals or exceeds a switch-selected level.

2. General Characteristics

The design philosophy and general appearance of the Auxiliary Processor were modeled after the basic MCF processor. The unit consists of an 80-in., single-bay rack containing three drawers: the arithmetic drawer, the output drawer, and the controller drawer (Figure I-1). As with the CPO MCF, all input and output cabling passes through the top of the cabinet

The spare rack space in the Auxiliary Processor may be used for support equipment such as the paper tape reader (PTR), data control modules, standard station timing unit, and the rack-mounted oscilloscope.

a. Input Signals

All input data signals are derived from the basic MCF processor as described in the following listing.

- Wiener Power Process

  This process derives its input from the MCF1-4 outputs. Of the 24 available bits of data, 9 are selected using of the input-data truncation switch.

- Fisher Process

  Single-channel data are accepted from the MCF0 output. This allows single-channel prefiltering of data prior to computation of the Fisher statistic. Of the available 24 bits of data, 9 are selected through the Fisher input-data truncation switch.

- UK Process

  The input is derived from two selectable beam-steer outputs. Nine of the total 24 available bits are selected by the UK input-data truncation switch.

b. Output Signals

The digital-to-analog converters used in the Auxiliary Processor are of the same type as those used in the MCF processor. For the Fisher, Wiener power, and UK outputs, 9 bits plus sign are selected from the 25-bit output register using individual output truncation switches, thus giving an analog-type gain control in 6-db increments.

The processor outputs are summarized as

- One Fisher output trace
- Two UK output traces corresponding to two programed area locations
- Four Wiener power traces corresponding to the MCF1-4 output traces
- One Fisher threshold trace corresponding to the Fisher output trace
- Four Wiener threshold traces corresponding to the four Wiener power traces

c. Program Selection

The following key variable programing modes are offered by means of panel-mounted switches.

- Fisher Process

  Normalization constants N1 and N2 are variable from 0 to 777_8. History length (gate length of computation) may be selected from 0 to 999 points.

- UK Process

  History length is variable from 0 to 999 points, and selection of the 4 beam-steers (2 each for UK0 and UK1) is provided.

- Wiener Power Process

  History length specifiable in R intervals, 0 to 99, and S samples, 0 to 99, where the gate is determined by R intervals of S samples each.

- Threshold Detectors

  Independently variable threshold levels are programable from 0 to 777_8.

B. HARDWARE EVALUATION

1. Reliability

The CPO Auxiliary Processor proved to be a highly reliable digital processing device. During the time the unit was operated at CPO from 30 December 1966 to 10 April 1967, not one failure occurred. This represents a total operating time of approximately 2900 hrs. Normally the "infant mortality" period, during which most failures are expected to occur because of marginal components, etc., is set at around 2000 hrs.

In future operations this unit should continue to be quite reliable since it consists entirely of solid-state hardware with the exception of the blower motor.

2. Maintainability

Little maintenance experience was gained on the unit due to the high reliability experience. Once installation and operational checkout was complete, processor maintenance was limited to routine operations which include periodic cleaning of the blower motor air filter and the daily step test (this test is also a part of the MCF maintenance procedure and completely varifies the Auxiliary Processor logic and arithimetic).

During the on-site installation and operational checkout phase, some maintenance knowledge was gained. The following empirical conclusions can be reached based upon this limited experience:

- The processor can be maintained by an individual trained in MCF maintenance if he reads and thoroughly understands the Auxiliary Processor Handbook.
- The computer wire list provided with the system is adequate, but somewhat cumbersome to use. Documents covering the MCF modification and interface were provided as "red-lined" changes on the original MCF documentation and, where applicable, references to this change list indicated.

3. Operation

Once the MCF Auxiliary Processor system was initially programed, adjustment was limited to daily changes of the threshold-level detection switches for the Fisher and Wiener outputs.

All MCF-Auxiliary Processor operations were performed by station analysts and technicians who had been briefed on the system operator controls.

4. Programming

Considerable difficulty was experienced in initially programing the Auxiliary Processor system. Some causes for this difficulty are as follows:

- Determination of the input data truncation switch setting for the Fisher Process requires knowledge of K1, K2, and K3. This information is not readily available.
- Determination of the Fisher intermediate summation truncate switch setting also requires knowledge of the size of the intermediate terms K1, K2 and K3.
- Determination of the Fisher transform constant N2 initially required detailed knowledge of the F values for the ambient noise and signal field.

- The method required to set the threshold level switches is cumbersome and highly inaccurate since it requires amplitude measurement of the Fisher and Wiener outputs on the Develocorder display.

Recommendations for simplifying setup and operation of the system follow. The threshold level adjustment problem is discussed in more detail in Section IV and the appendix.

C. RECOMMENDATIONS

In order to simplify initial set-up and operation of the Auxiliary Processor system, the following changes are recommended for possible future systems. Most of these could be easily incorporated into the existing hardware with only minor modifications. The threshold detector change is considered essential for proper operation of the system as an automatic detection device. Recommended changes are

- Setting the Fisher transform constant N1 to a fixed value of 777_8 in order that the maximum Fisher output value will equal the maximum output number (9 bits). Gain control would still be available in the Fisher D-A switch.
- Setting the Fisher transform constant N2 to a fixed value of 20_8 since, from what is now known about the expected size of F for array data, this value insures adequate number significance between true Fisher values and transformed Fisher output values (Figure III-1).
- Providing a test mode for displaying the Fisher intermediate terms K1, K2 and K3 in order to facilitate setting the Fisher input and intermediate data truncation switches. These terms could be displayed on the Wiener power outputs when in the test mode.
- Providing an input channel selection capability for the Fisher input. At present all MCF input channels used in any beam-steer output are used in the F computation. For example, if it were desired to input a 3-component sensor to the MCF for the purpose of frequency filtering, delaying and displaying adjacent to the MCF data, these inputs would at present be included in the F computation.

- Modifying the threshold level switches for the Wiener and Fisher outputs to be adaptive rather than fixed.

SECTION IV

EVALUATION OF ON-LINE PROCESSING

The primary objective of the Auxiliary Processor on-line evaluation phase was to determine the feasibility and effectiveness of on-line automatic detection processing. As an integral part of this evaluation, it was intended that data be developed demonstrating the interdependence of detection threshold and false-alarm rate. From this data the two detection processes, Fisher analysis of variance and Wiener power, could be compared for detection capability. Data from the two UK outputs were to be studied using the British Classification scheme.

The following paragraphs describe in detail the on-line evaluation phase. For continuity, a description of the processor operating configuration is presented first. Data for this phase was developed primarily by station personnel as a part of the routine observatory operation.

A. AUXILIARY PROCESSOR PROGRAM

The Auxiliary Processor was operational on line at CPO from 30 December 1966 to 17 April 1967. Table IV-1 presents a summary of the fixed program employed in the digital MCF and Auxiliary Processor during this time period. Table IV-2 presents a summary of the MCF's and beam steers employed in the processor.

As indicated in Table IV-1, the threshold levels were varied daily. Integration gate lengths for all outputs were initially programed for 2-sec, but were changed to 3-sec (60-pts) on 14 February 1966. This change in gate length computation was based upon a study of mean-signal-length conducted in Dallas. The Fisher, Wiener and UK computations are optimized when the gate length of integration equals the P-wave duration. A mean P-wave duration of 2.9 sec was determined (SectionV).

B. DETECTION PROCESSING

Results from on-line analysis of the detection outputs indicate that the Fisher and Wiener processes were properly implemented and that this type of on-line computation may be highly effective in automatic P-wave detection. Quantitive data demonstrating the effectiveness of the present system could not be obtained due to the effect of non-time stationary Fisher and Wiener Power noise distribution on the threshold detection outputs.

Table IV-1

PROCESSOR PROGRAM DATA

MCF PROCESSOR

Channels	19
Filter points	57
Multichannel filters	5
Beam-steers	9
Signal conditioner	All 0's
D-A converter	Channels 0 to 4 = -3 Channels 11 to 14 = -3
Beam-steer history	15
Time delay	28

AUXILIARY PROCESSOR

Arithmetic drawer	UK0	56
	UK1	78
	UK history	60
	Fisher N1	177_8
	Fisher N2	20_8
	Fisher history	60
	MCF power	R = 60, S = 1
Output drawer	UK0	-3
	UK1	-3
	MCF0	-4
	MCF1	-4
	MCF2	-3
	MCF3	-3
	Fisher	-15
Data truncation switches	Fisher	-3
	UK	-2
	MCF power	-2
Fisher summation truncation switch		-7

Note: UK0 and UK1 are absolute magnitude. Threshold switches are varied on a daily basis.

Table IV-2

PRESENT PROCESSOR OPERATING MODE

Title	Description
BS0*	Straight sum (Z1 - Z19)
BS1	North, velocity = 12.6 km/sec (Z1 - Z19)
BS2	East, velocity = 12.6 km/sec (Z1 - Z19)
BS3	South, velocity = 12.6 km/sec (Z1 - Z19)
BS4	West, veloctiy = 12.6 km/sec (Z1 - Z19)
BS5**	In-line summation toward USSR using Z4, 6, 7, 9, 14, 15, 17, and 19
BS6**	Transverse summation toward USSR perpendicular to BS5
BS7**	In-line summation approximately toward NTS using Z1, 2, 8, 10, 11, 12, 13, and 18
BS8**	Transverse summation approximately toward NTS perpendicular to BS7
MCF0*	0.75 cps low-cut filter
MCF1	MCF3† convolved with 1.0- to 2.0-cps bandpass filter
MCF2	IP10WGS† convolved with 1.0- to 2.0-cps bandpass filter
MCF3	MCF3†
MCF4	MCF24†

* MCF0 subsection prefilters the 19-channel data and presents it for use in the BS subsection.

** Used as inputs to UK0 and UK1 of Auxiliary Processor.

† A complete description of the filters is discussed in Appendix A of CPO Annual Report No. 1.

1. Automatic Detection

Two basic problems which arose at CPO in attempting to implement and evaluate automatic on-line P-wave detection with the Auxiliary Processor system are

- The defined detection threshold for a fixed false-alarm rate* was highly variable. Variations as great as 3 to 6 db were observed during a single day.

- The method used for rapid determination of the threshold levels for automatic detection was, at best, inaccurate and cumbersome.

The two problems actually interrelate to the extent that the time variability problem could have been partially overcome by adjusting the detection threshold settings often (each hour), but a rapid and accurate technique for determining the desired threshold level for a fixed false-alarm rate was not available with the existing hardware and setup. The inaccuracy of the threshold determination techniques could have been overcome by a slow process of recording outputs on FM tape and conducting off-line analysis to determine the desired levels, but this was useless due to the non-time stationarity of the Fisher and Wiener power output noise distribution.

a. Threshold-Level Problem

A procedure was adopted at CPO to update the threshold levels on a daily basis (or more often, if required). This procedure, although inaccurate, did establish an approximate representation of the output noise distribution in terms of the daily threshold-level setting. Threshold levels for the Fisher output and the four Wiener power outputs are shown in Figure IV-1 for most of the period the processor operated at CPO. The level variability is evident in this figure.

The exact cause of the variation in output levels is not known at this time; however, it is reasonable to suspect several sources. In the case of the Fisher process, changes in the mantle P-wave noise level and in the level of the trapped-mode noise are probably the most significant contributors. Mantle P-wave noise variability as well as changes in trapped-mode noise direction could effect the Wiener detection outputs.

Results from the CPO noise analysis[4] indicated that the predominate trapped-mode noise components remained stationary over the analysis period. However, indications were that the intensity of the various components varied; such a variation would reasonably affect the Fisher distribution.

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* As used in this report, fixed false-alarm rate is defined as the number of false-alarms per events detected as a function of time.

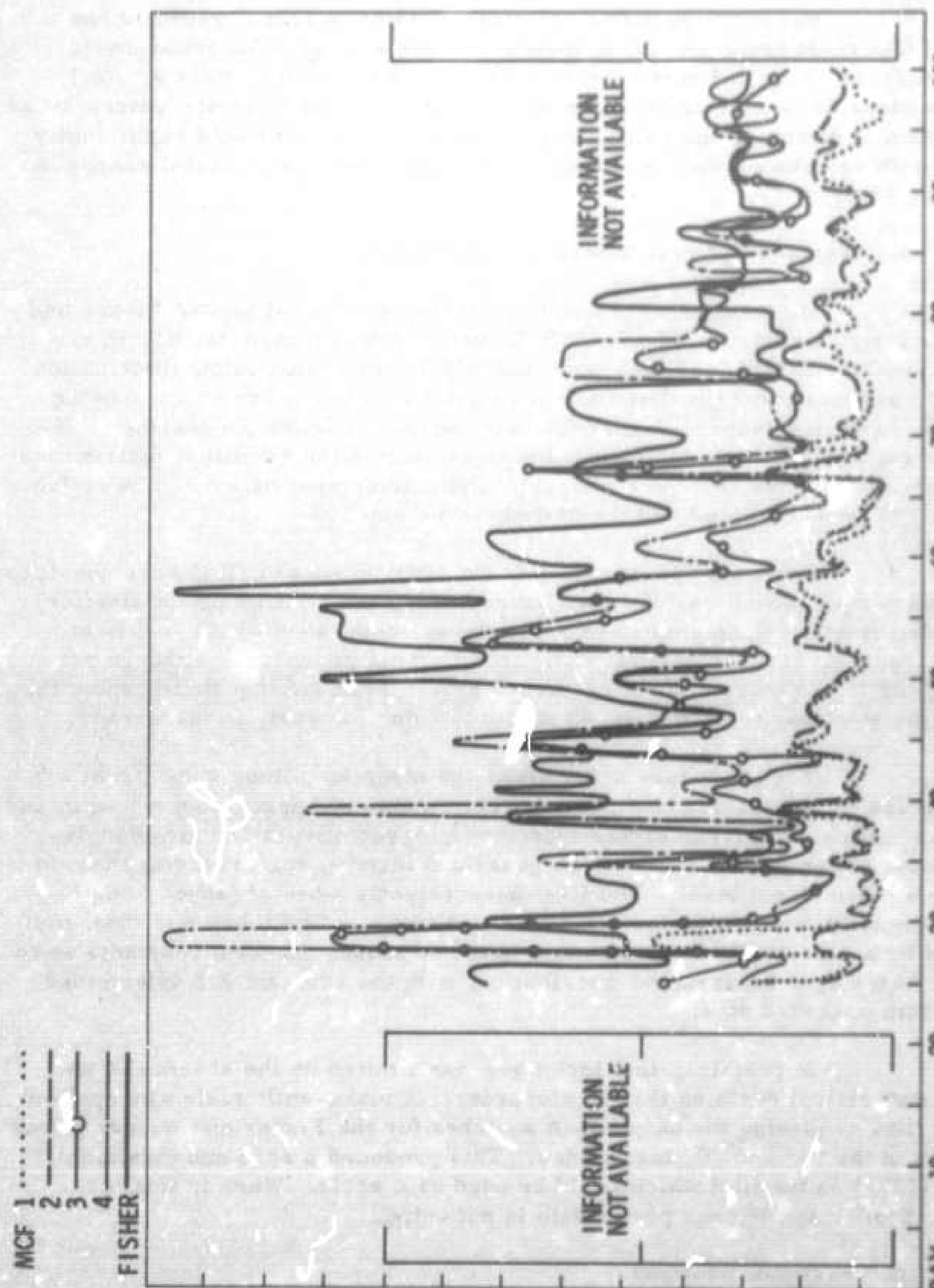


Figure IV-1. CPO Daily Threshold Levels

Recent work under contract AF 33(657)-12747[5] revealed one source (the most predominate) of mantle P-wave energy to be atmospheric low-pressure areas and storm centers (hurricanes, tropical storms, etc.). It is reasonable to assume the level of this energy would fluctuate noticeably as a function of distance, intensity and possibly direction and would significantly affect both detection output levels due to the coincidence with signal energy in velocity space.

b. Threshold-Level Determination Problem

Determination of the desired threshold level for the Fisher and Wiener power outputs would normally be based upon a fixed false-alarm rate which could be determined from knowledge of the detection output distribution values, assuming that the distribution remains stationary over a reasonable period, such as a season. Under this assumption, off-line processing of detection output data would be reasonable to determine the amplitude distribution and subsequently the desired threshold. Detection output data could be collected on FM tape, digitized and the distribution computed.

Since the apparent amplitude distributions at CPO were non-time stationary over periods as short as hours, ruling out off-line processing for level determination, an on-line procedure was established which, in effect, was a trade-off between accuracy and speed. This procedure, although performed daily and more often if required, proved to be inadequate to handle the non-time stationarity problem. Probably this due, in part, to inaccuracy.

The procedure determined the mean amplitude value from a 5-min period of noise using five noise measurements at approximately 1-min intervals. Each measurement was made over 10 sec of data and involved determining the amplitude value of the peaks and troughs and arranging them to obtain a mean output level. The five measurements were arranged to determine the daily mean value for each detection output. The mean was then multiplied by a constant to determine the threshold value. Several constants were tried, based upon an assumed distribution, with the constant 2.5 determined best from observed data.

In practice, this technique was limited by the absence of an accurate vertical scale on the Develocorder. A make-shift scale was applied to the film by placing the output D-A switches for the Fisher and Wiener power outputs in the "+" and "0" test modes. This produced a zero and maximum value (777_8) on the film which could be used as a scale. When in this test mode, Fisher and Wiener power data is not output.

c. Recommendations

Automatic detection could be properly implemented if the

threshold levels could be varied accurately and rapidly to compensate for distribution changes in the Fisher and Wiener power outputs. A suitable approach would be the incorporation of an adaptive threshold device into the existing hardware which could be made to adapt to data history, thus insuring a relatively consistent false-alarm rate. By using an on-line adaptive algorithm to update the threshold levels constantly, problems in measuring distribution, etc. could be avoided. Only the specification of a constant multiplier to be applied to some output property such as the mean value would be required.

The appendix presents an adaptive threshold algorithm which is recommended for incorporation into the existing Auxiliary Processor.

2. Visual Analysis

Since problems were encountered using the automatic detection thresholds, an attempt was made to analyze the Wiener power and Fisher outputs for detection purposes. This proved to be unsatisfactory to the station analysts because the effect of smoothing of the integration gate destroyed signal energy content and waveform, and made the transition from noise to signal areas for small events quite gradual contrasted to the normal sharp break detectable for a P-wave arrival. Also, the "event signatures", which were commonly used to detect low-level signals, were not easily recognized after detection processing.

In addition, the absence of a zero level for each of the traces made it difficult to determine visually relative amplitude on the trace data.

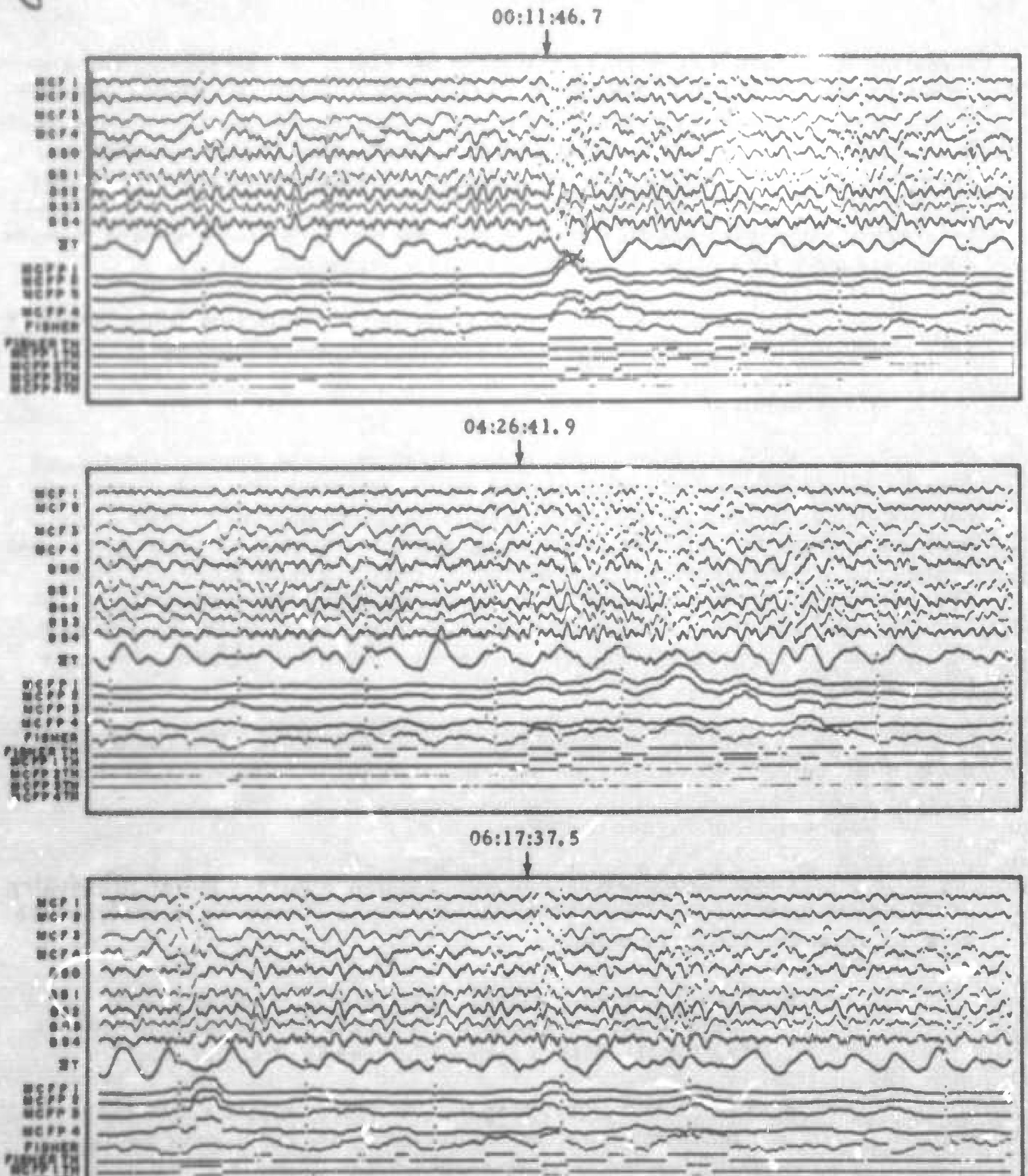
3. Comparison of Fisher and Wiener Power

Limited comparisons of the Fisher and Wiener power processing at CPO were made by the observatory analysts while attempting to analyze this data for event detection, including:

- For high velocity signals, the ratio of the peak-signal output to the RMS statistic is larger for the MCF processes than for the Fisher output (Figures IV-2 and IV-3.)

- The Fisher signal response to quarry blasts shows the Fisher outputs to be unaffected by P- and S-wave energy falling in the velocity ranges 6.1 to 8. km/sec and 3.25 to 3.51 km/sec, respectively (Figure IV-4).

The Fisher signal response property was also investigated in off-line research (Section V) and found to decrease rapidly with increasing wavenumber. This property proved quite useful at CPO for distinguishing local and near regional events from teleseismic P-wave energy and on several oc-



JANUARY 6, 1967

Figure IV-2. Data Processed by the MCF and Auxiliary Systems During Known Signal Conditions

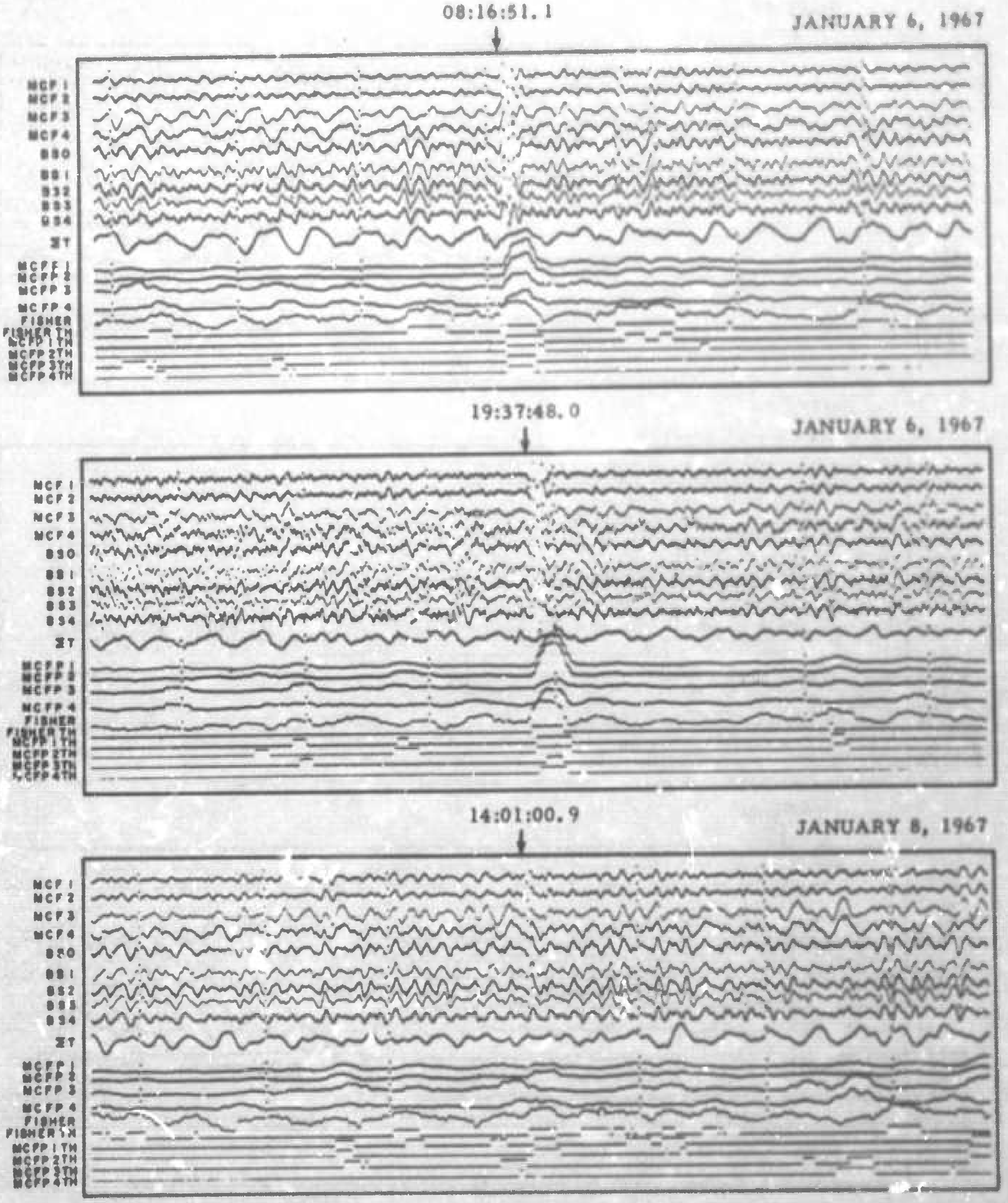
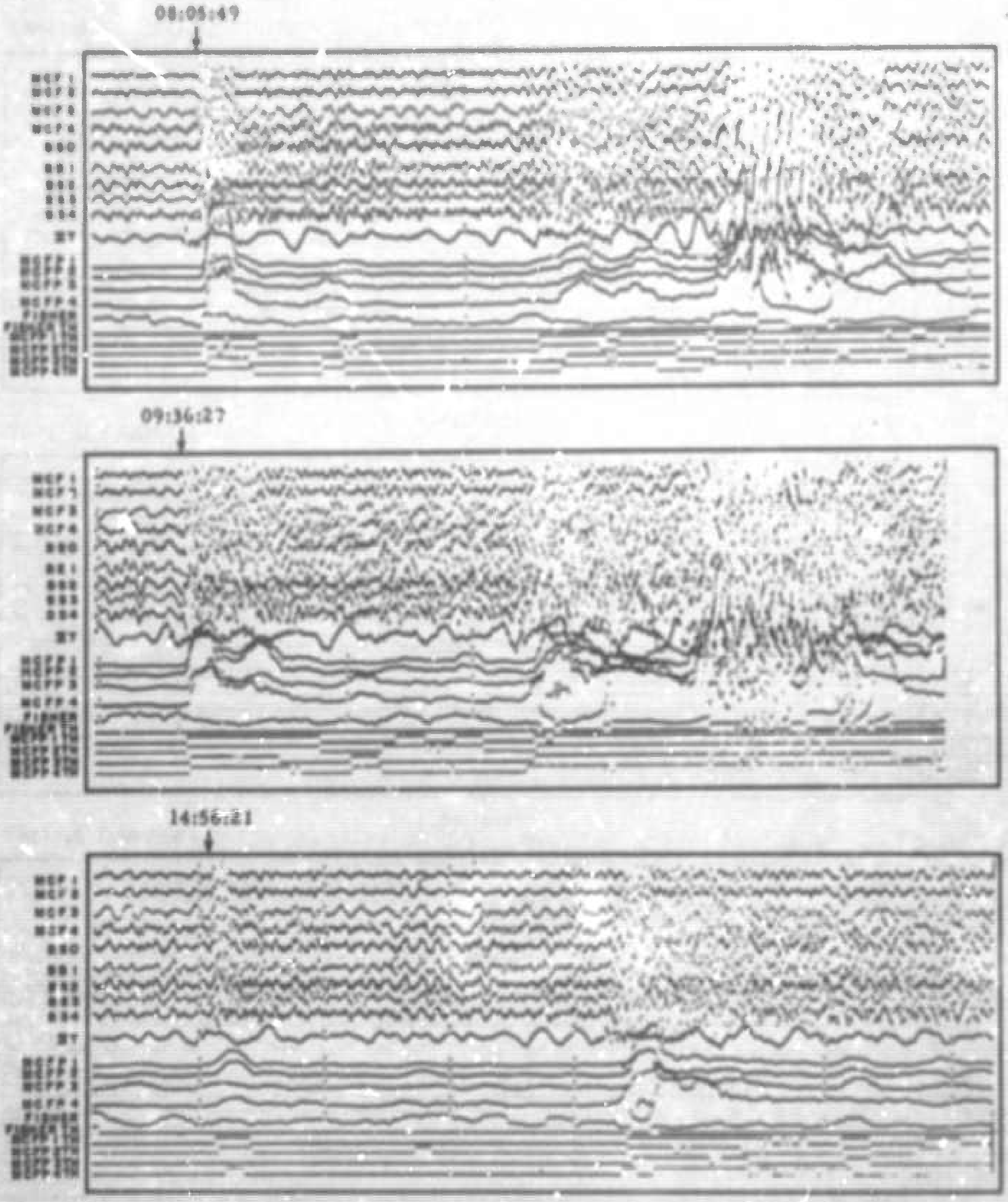


Figure IV-3. Data Processed by the MCF and Auxiliary Systems During Known Signal Conditions



JANUARY 6, 1967

Figure IV-4. Three Quarry Blasts Processed by the MCF and Auxiliary Systems

casions aided in detecting teleseismic P-wave energy during quarry blast arrivals.

C. UK PROCESSING

Analysis of the two UK outputs at CPO indicated that the British Classification scheme could be effectively applied on-line. However, three limitations exist, two caused by the present implementation and the other caused by CPO noise properties. These limitations are

- The two UK outputs are computed from a fixed program which in essence restricts classification work to two signal sources. At CPO the outputs were computed for NTS and for Russia.

- Classification based upon the UK scheme requires preservation of signal waveform. The MCF Auxiliary Processor system is limited to 72-db dynamic range on input (12 bits). Since this system is used primarily for detection based upon suppression of coherent noise, the input noise level must be sufficiently high to insure adequate noise statistics for MCF processing. Thus, large signals are clipped on input or during intermediate computations.

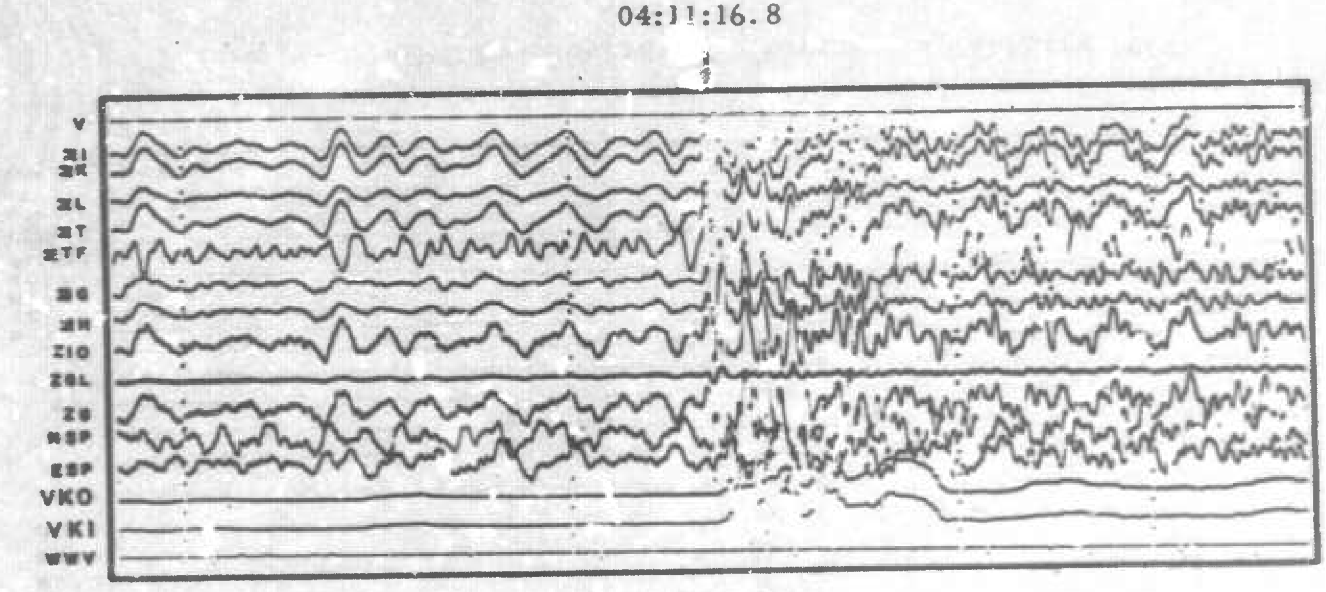
- The UK technique is designed for application to intermediate size crossarray data (approximately 20 km) to insure adequate resolution and an uncorrelated ambient noise field. The CPO array (3.6 km dia) violated the assumption of uncorrelated noise and provided very poor directional-velocity resolution.

At CPO the UK portion of the processor was programed for maximum waveform preservation within the limitation of having the input data gain setting optimized for MCF programing. Thus, the UK input data truncation switches were set such that a 12-bit signal on input to the MCF (maximum P-P without clipping) would be processed by the UK computation and output without clipping. This set-up was considered optimum for the classification computation since waveform preservation is most important. However, with the Develocorder adjusted to a measurable gain level, modulation of low-level signal was poor.

Examples of UK output data for the two programed signal regions are shown in Figures IV-5 through IV-9. These figures demonstrate the dynamic range limitation. Figure IV-7 presents an example of a quarry blast processed by the UK technique. For this blast and for the special event

in Figure IV-5 the P-coda rapidly decays, as expected.

Because of the limitations discussed above, sufficient data were not collected under this task to conduct study of the UK classification scheme.



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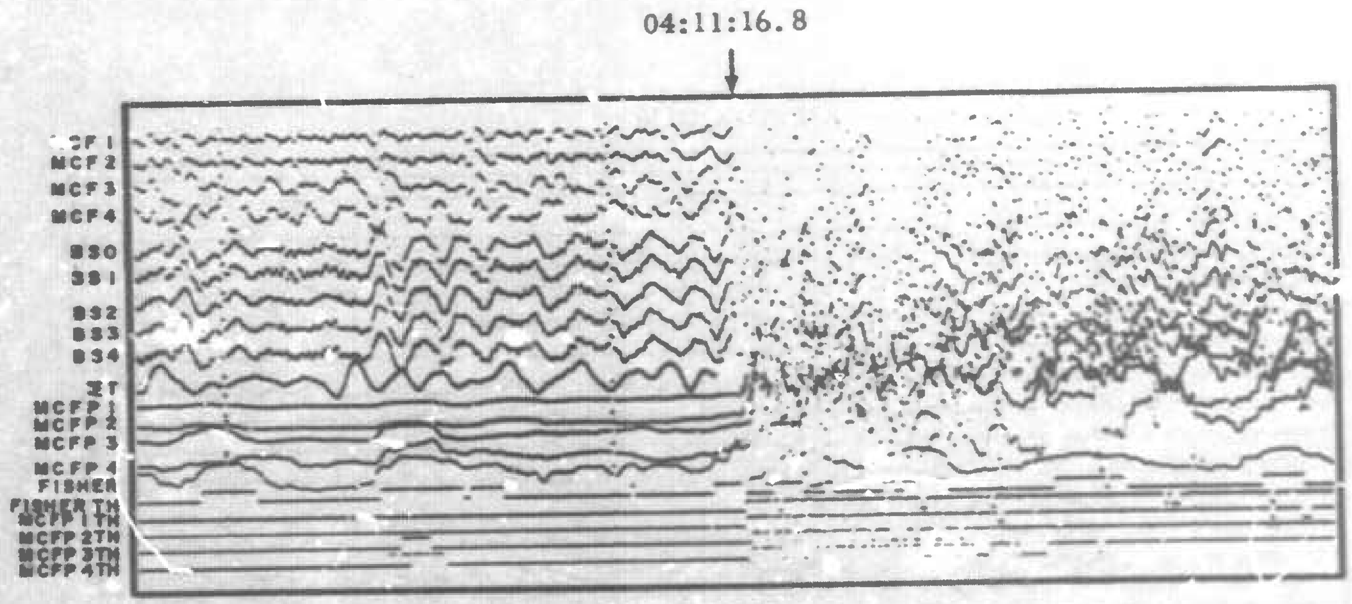

MCF

Figure IV-5. C. O Develocorder Recordings, 26 February 1967

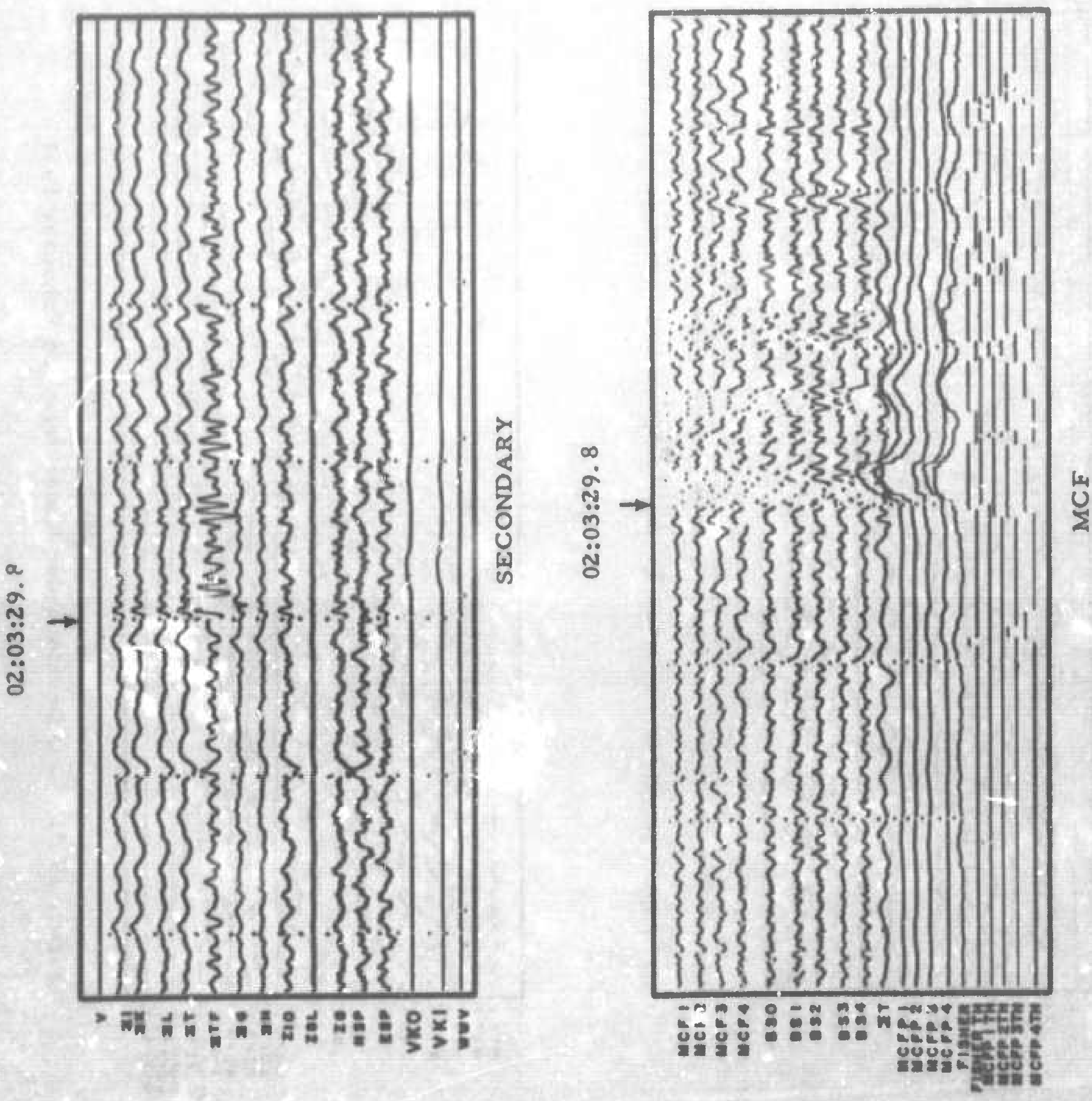

Figure IV-6. CPO Develocorder Recordings, 3 February 1967

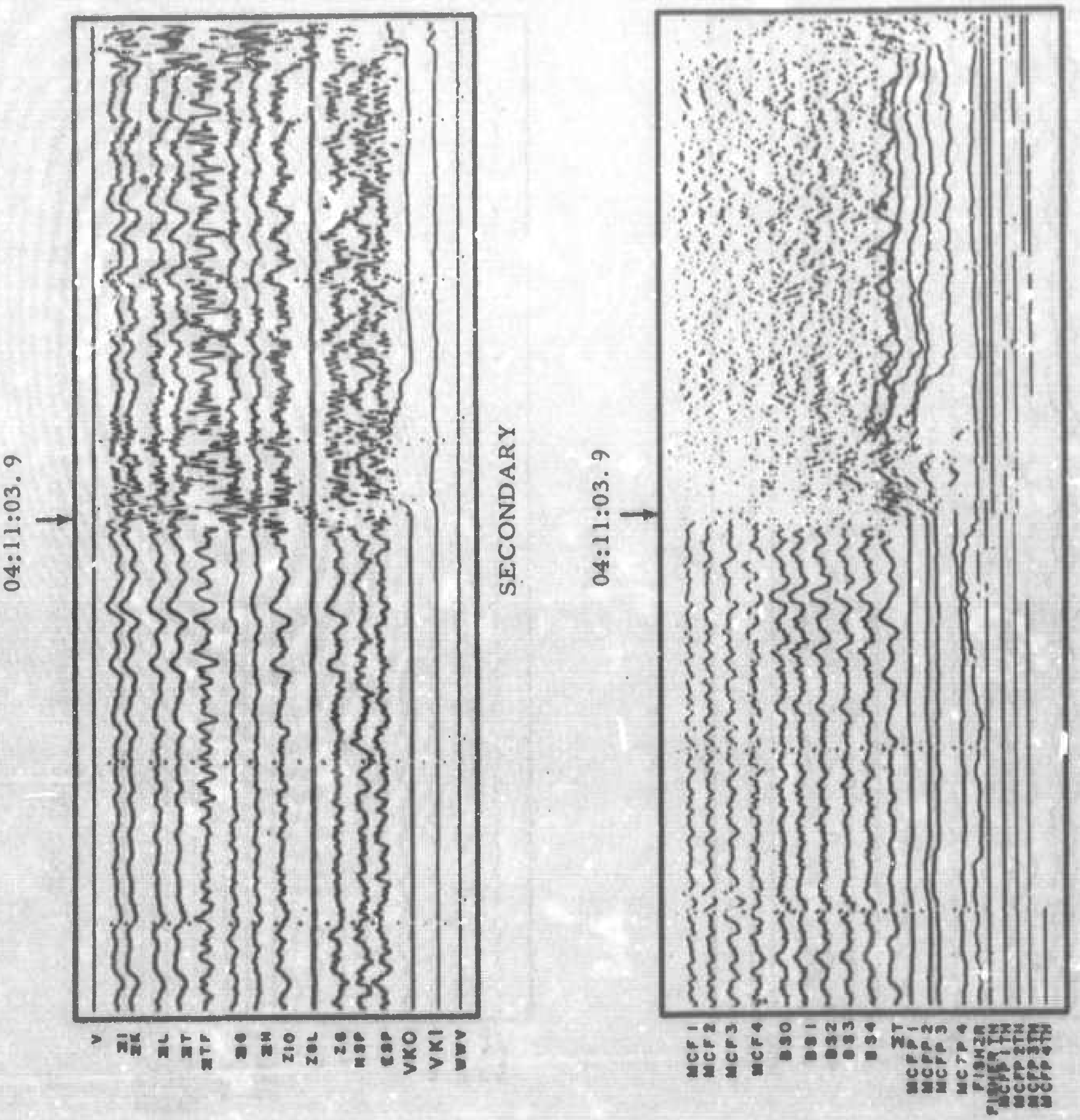

Figure IV-7. CPO Develocorder Recordings, 27 February 1967

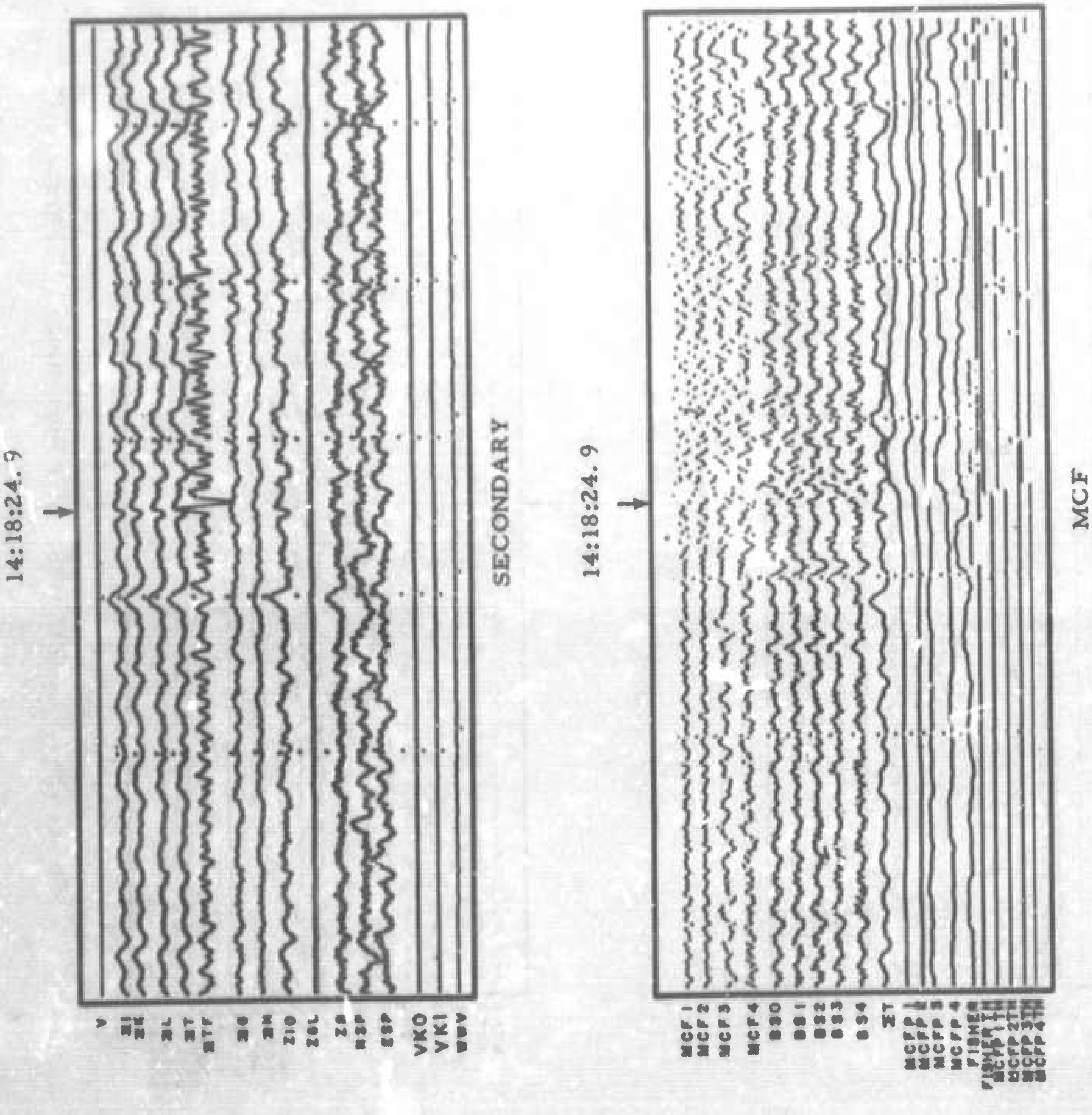

Figure IV-8. CPO Develocorder Recordings, 2 March 1967

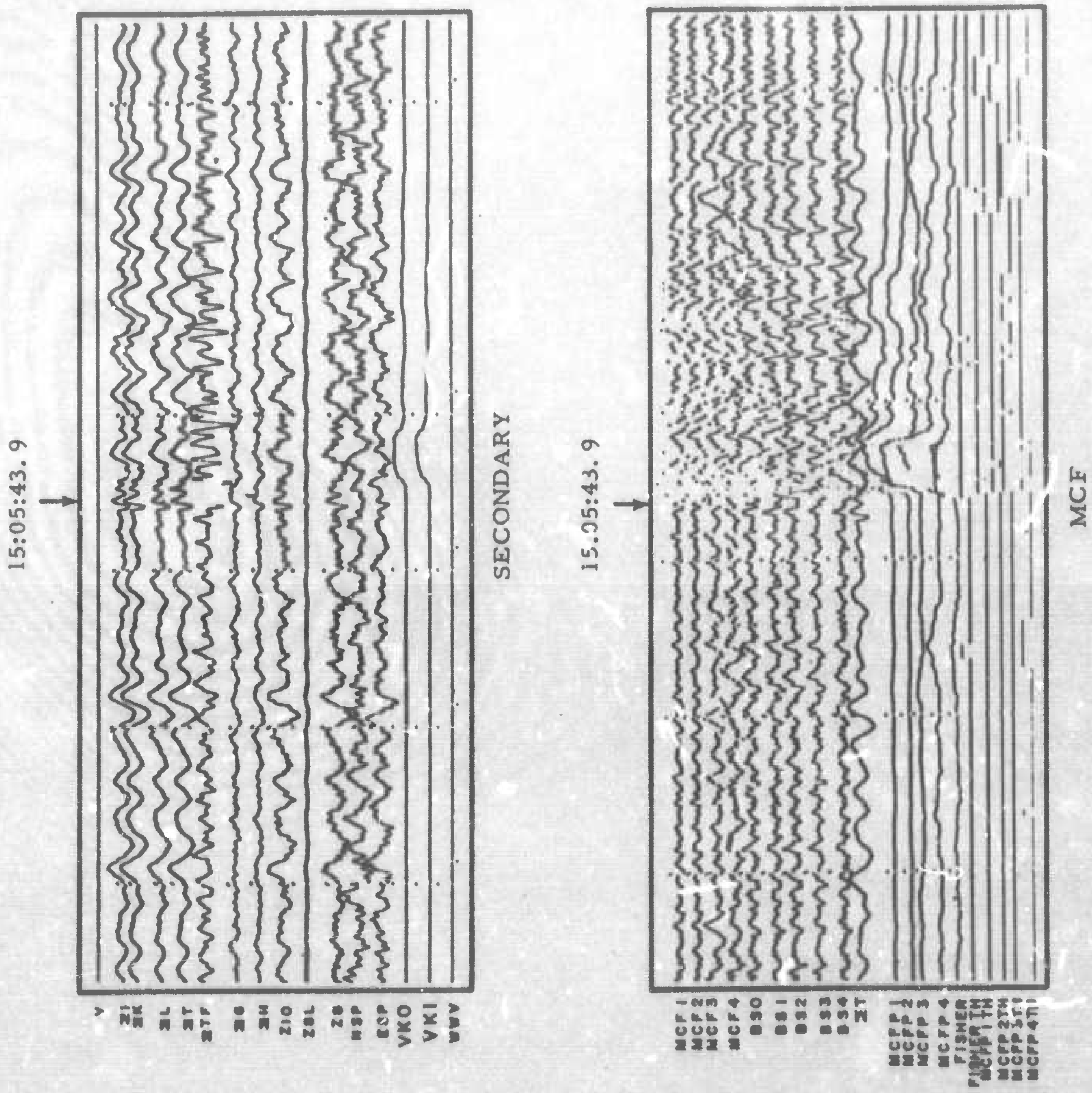

Figure IV-9. CPO Develocorder Recordings, 22 March 1967

SECTION V

SUPPORTING DETECTION PROCESSING RESEARCH

In conjunction with on-line operation of the Auxiliary Processor, off-line research was done in Dallas. Primary research goals were to verify the logic of the Auxiliary Processor, to determine and study and parameters used with the different processes, and to study the effects of varying these parameters.

A. PROCESSOR SIMULATION PROGRAM

A simulation program to study the processor logic was written which used the IBM 7044 computer. This program simulated the logic of both the MCF and Auxiliary Processor and checked for round-off errors in the processor computations. A complete description of the program may be found in CPO Special Report 3.[6]

B. THEORETICAL NOISE SAMPLE

To provide representative CPO ambient noise statistics for use in studying the Fisher statistic while minimizing computer requirements (i. e., number of noise samples required for processing) a 5000-pt theoretical noise sample was synthesized. This sample was designed to have the same correlation matrix as the CPO noise-ensemble samples A, B, E, F, and I, developed under Contract AF 33(657)-12331. Due to the noise field time stationarity (CPO Special Report No. 1[4]), it was felt that this 1963 average noise ensemble would provide a statistical representation of the CPO ambient noise field.

The technique used to develop this noise sample (Figure V-1) is discussed in Section III of the Array Research Semiannual Report 3[7]. After the data were developed, the noise sample was tested for the same properties as the desired correlation matrix. Power spectra were computed from random correlations using both the theoretical and original noise samples. These power spectra (Figure V-2) show that the theoretical noise sample has the same properties as the original noise sample and does represent true seismic data.

C. PROCESSING PARAMETERS

Choice of correct operating parameters is of primary importance in on-line operation of the Auxiliary Processor. Research in Dallas has resulted in optimizing two critical parameters: the signal gate length and corner frequency of MCF0 which is the prefilter for the Fisher process.

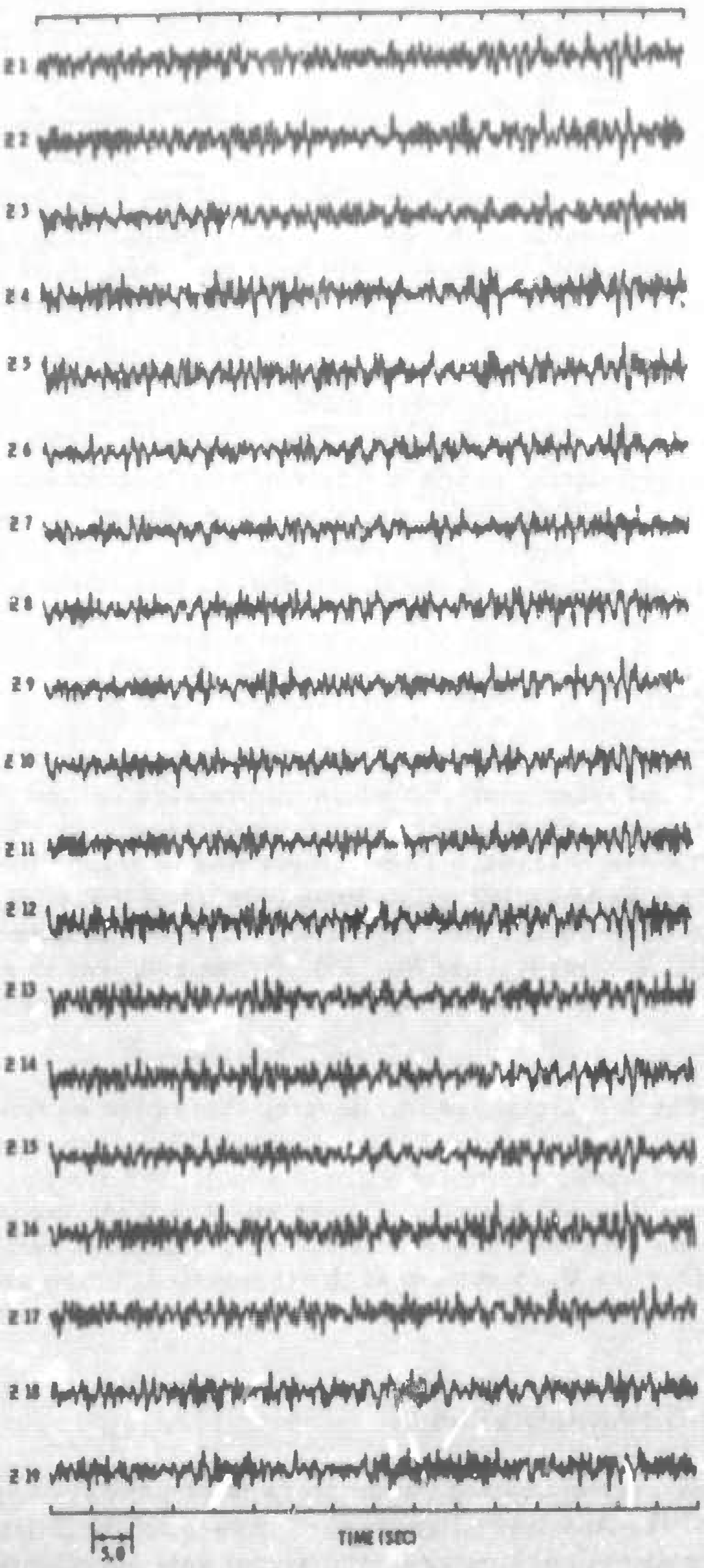

Figure V-1. CPO Theoretical Noise Sample

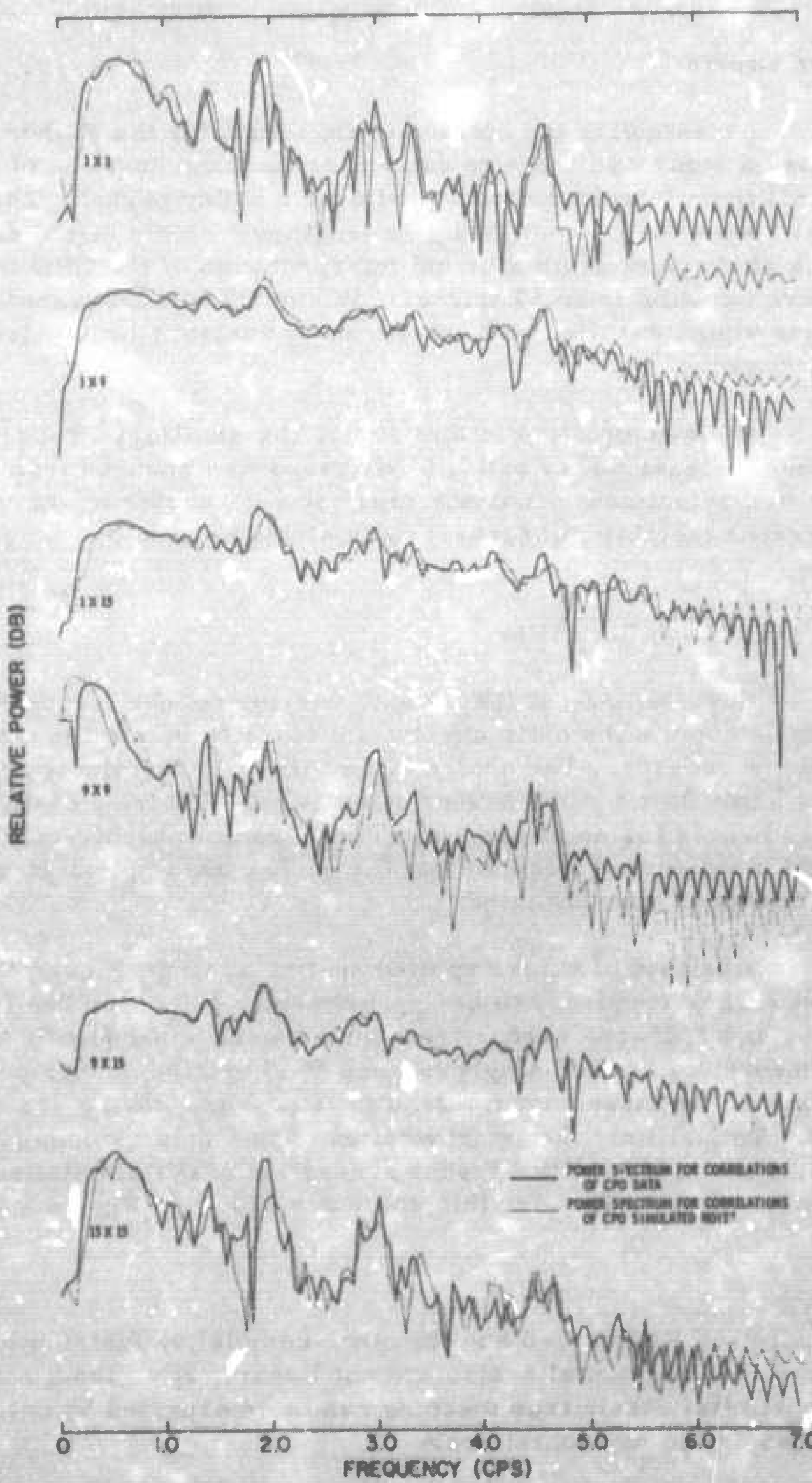

Figure V-[illegible]. Power Spectra Comparing Theoretical and Original Noise Samples

1. Gate Length

To establish the optimum gate length for the Fisher and Wiener computations, a study was made to determine the time duration of the primary P-wave signal from teleseisms recorded over a 6-day period. The processes are optimized when the computation gate length equals the signal duration. Data for this study came from a visual interpretation of the CPO Develocorder film. P-wave duration from 57 teleseismic signals was measured, yielding a mean P-pulse signal duration of 2.90 sec and a variance in P-pulse signal duration of 1.90 sec.

Upon completion of this study, the Auxiliary Processor program for the Fisher, Wiener power and UK processes was changed from 2.0 to 3.0 sec. After this adjustment, analysts reported data easier to analyze, since the processed traces (notably the Fisher) were stabilized and did not correlate as well in time.

2. Optimum Low-Cut Filter

Several low-cut filters with varying corner frequencies were developed to determine the optimum low-cut filter to be used in the MCF0 subsection of the processor. The choice of this filter is extremely important since it is the prefilter for the Fisher subroutine. Filtering of the input data to the Fisher process is necessary in order to remove highly-correlated low-frequency microseismic energy so that the Fisher assumption of spatially uncorrelated energy is approximated.

Analysis of filters applied on-line at CPO (Figure V-3) showed the optimum corner frequency to be approximately 1.0 cps. The filters with 0.75-, 1.0-, and 1.25-cps corner frequencies were subsequently applied off-line to the theoretical noise sample (Figure V-1) and the Fisher output computed for each of the three cases. Results of this processing are shown in Figure V-4. To facilitate the interpretation of this data, a cumulative-distribution counter was added to the Fisher subsection of the simulation program.[6] The cumulative distributions for this study are shown in Figure V-5.*

*When interpreting Figure V-5 and the other cumulative distributions presented in this report, the horizontal scales are not linear. Even though the curves may appear very similar, their true meaning can be interpreted by noting the last several inches on the horizontal scale.

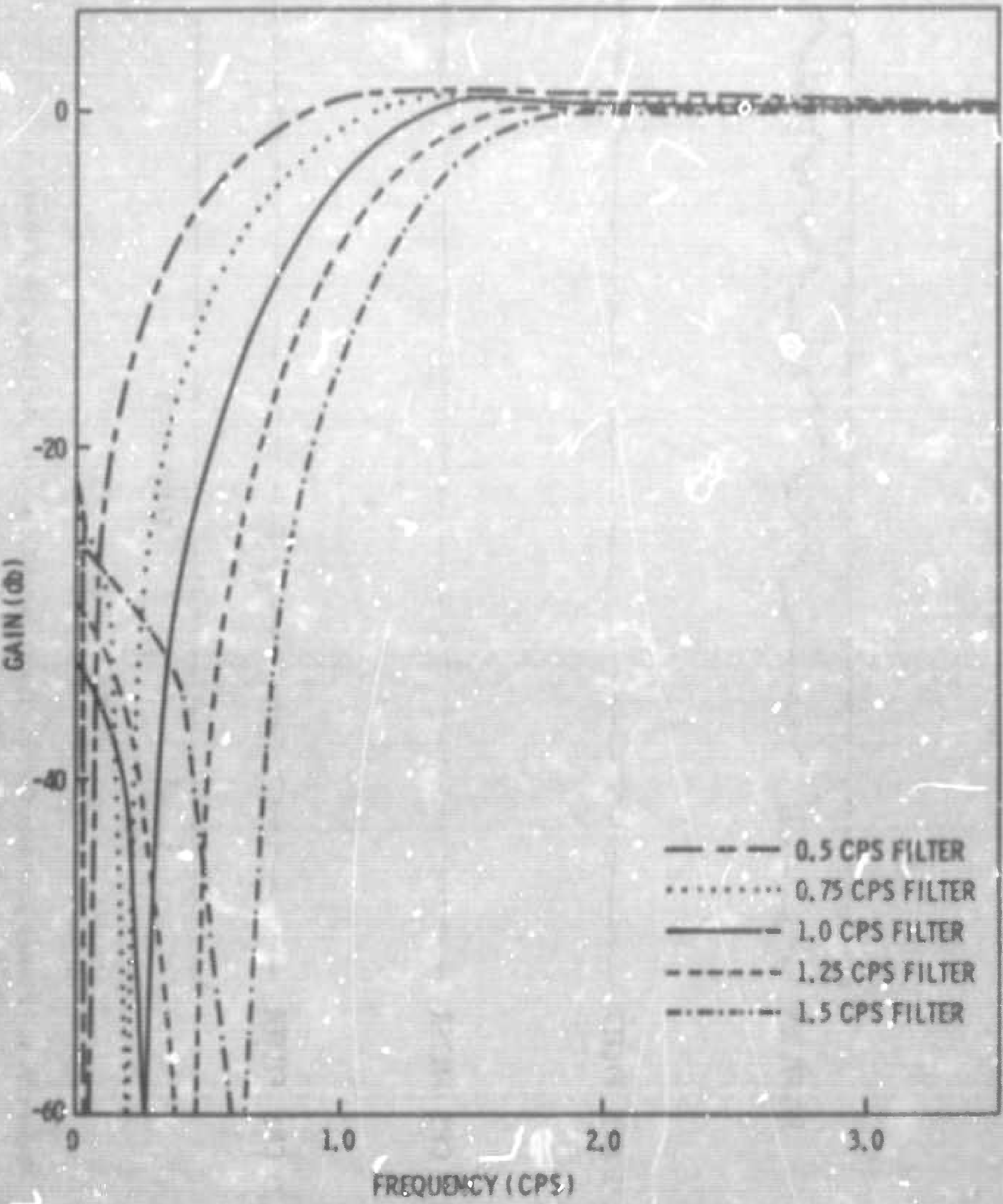

Figure V-3. CPO MCF0 Low-Cut Prefilters

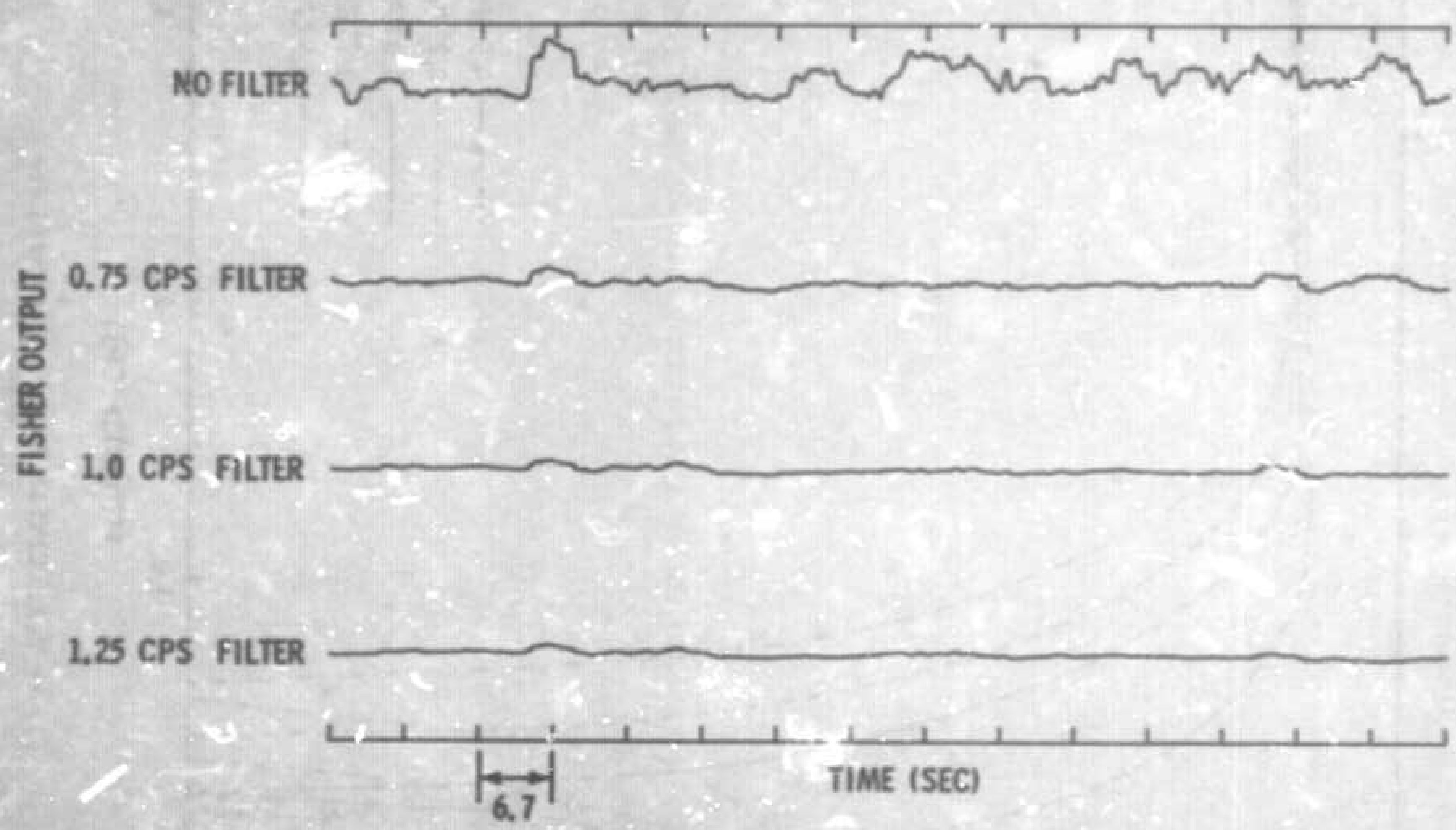

Figure V-4. Fisher Statistic for the Theoretical Noise Sample Using No Filter, 0.75-, 1.0-, and 1.25-cps Low-Cut Filters

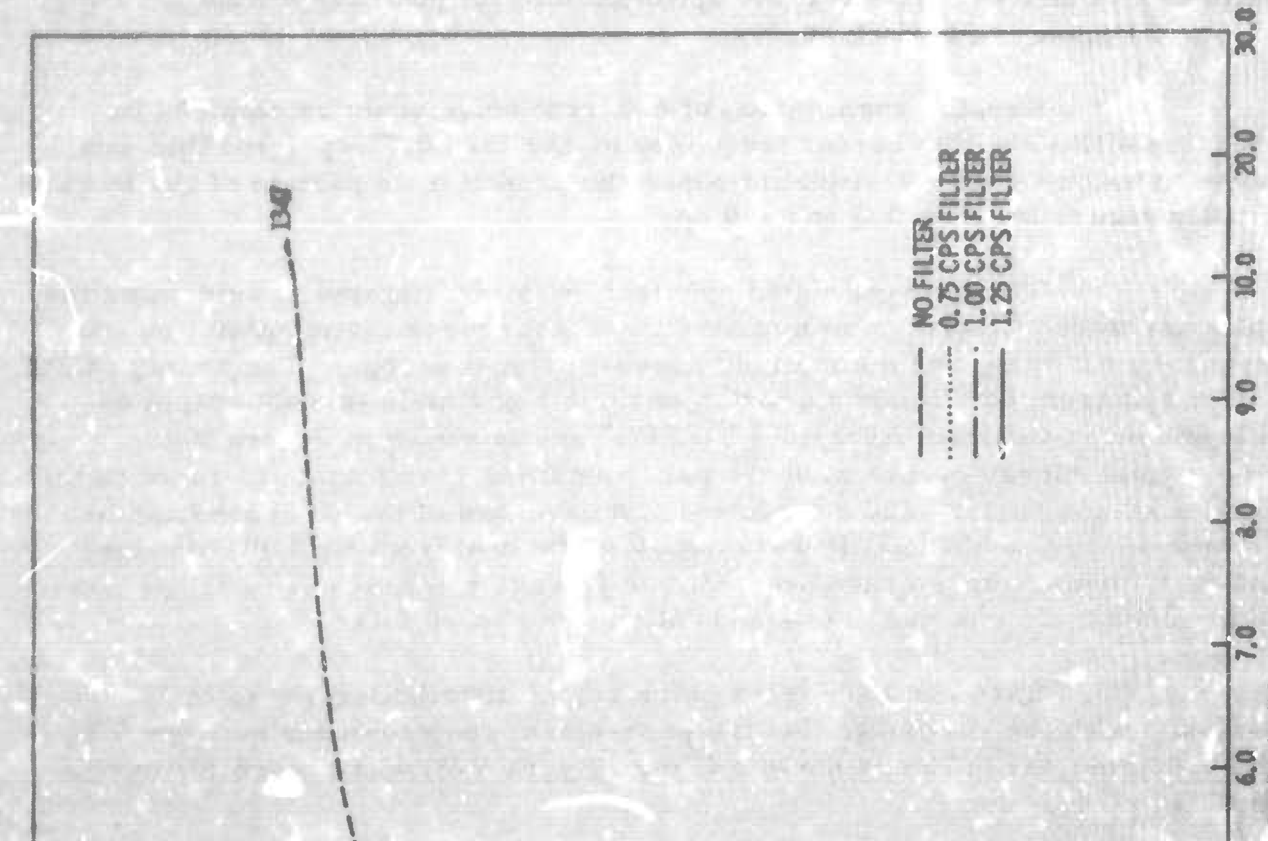

Figure V-5. Cumulative Distribution for Fisher Statistic for Theoretical Noise Sample Using No Filter, 0.75-, 1.0-, and 1.25-cps Low-Cut Filters

Figures V-4 and V-5 show that the optimum low-cut prefilter should have a corner frequency of 0.75-1.00.*

Greater suppression of coherent noise could be obtained by choosing a filter with a corner frequency higher than 0.75 cps, but this would cause extensive signal degradation since the predominate portion of the P-wave usually occurs between 0.6 and 1.0 cps.

The average signal spectrum was investigated to determine the optimum trade off between minimizing the Fisher noise distribution (low-cut frequency filtering) and maintaining adequate signal energy. The average CPO signal spectrum was computed for an ensemble of Kurile Islands events developed under Contract AF 33(657)-12747 [8] and is shown in Figure V-6. Peak signal energy occurs at 0.68 cps. Since this result could be tuned to the Kurile Islands region, and not represent an average of the CPO predominant P-wave energy, additional P-wave data was derived from the CPO standard analysis forms. An average predominate P-wave frequency of 0.82 cps was determined from one month of standard station report data.

Based on the Fisher noise output distribution shown in Figure V-5, and with the knowledge that the peak-signal spectrum lies between 0.68 and 0.82 cps, the 0.75 cps low-cut filter (Figure V-3) was chosen for on-line application.

D. PROCESSED NOISE SAMPLES

1. Threshold Non-Time Stationarity

The Fisher output noise distribution non-time stationarity was studied. Four noise samples, I, II, III, and IV, were chosen for processing from the 1965 CPO library (Figure V-7) and represent the different types of noise backgrounds encountered at CPO (low-I, medium-II and III and high—IV). Power density spectra for these samples are shown in Figure V-8. The Fisher statistic for the four samples is shown in Figure V-9, and the cumulative distributions for the Fisher statistics are shown in Figure V-10. These illustrations show the Fisher statistic to be larger for high noise (Sample IV) and smaller for the other samples.

Although Sample I is of low-level noise, its Fisher statistic is larger than those from Samples II and III. While the cause for this is unknown, it is possible that the mantle P-wave noise level was much higher for Sample I

*The theoretical noise sample (Figure V-1) has been prewhitened with a 1.0 cps 12 db/octave low-cut filter which closely approximates the frequency filtering accomplished on the MCF analog output data in the MCF signal conditioning drawer.

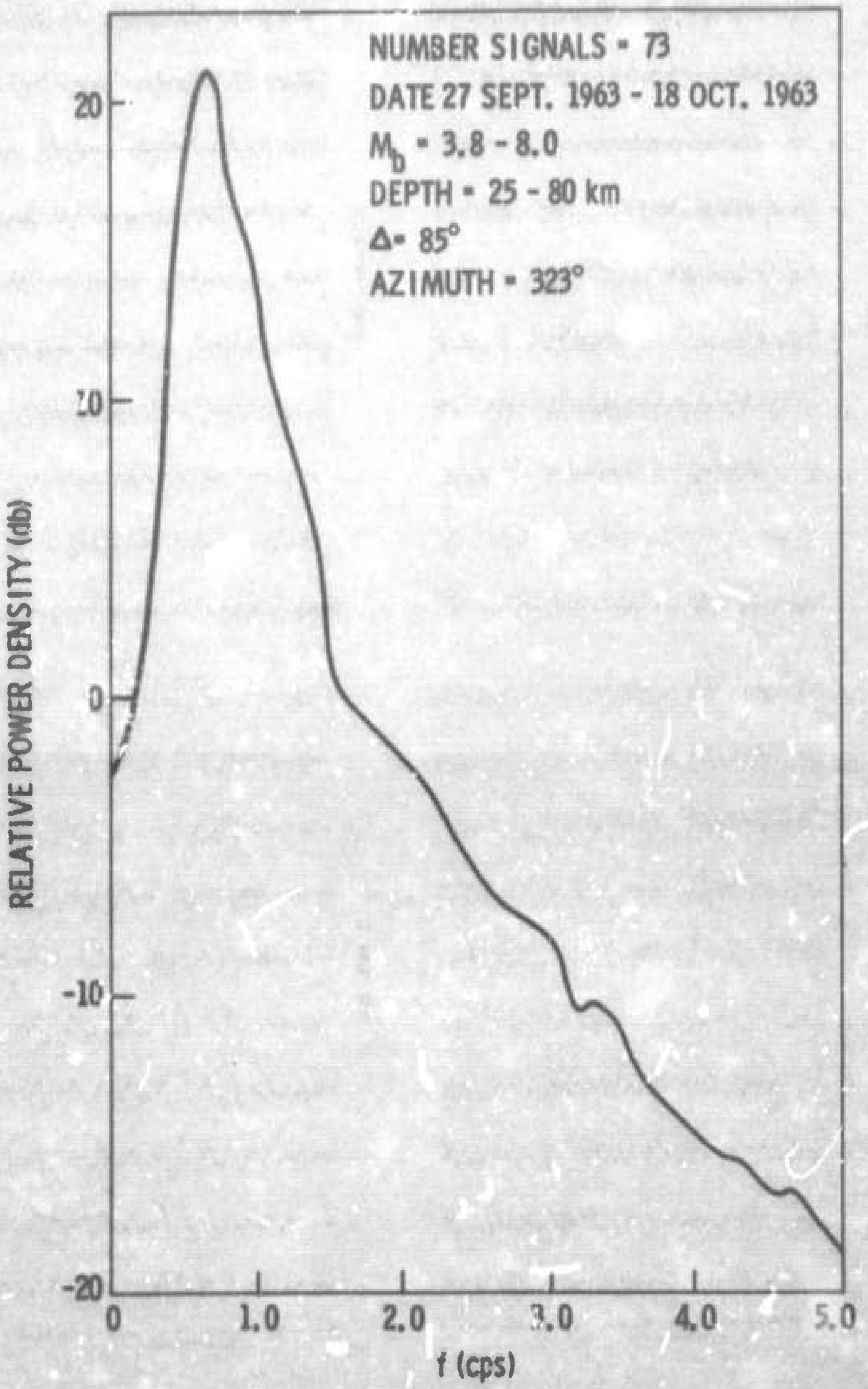

Figure V-6. CPO Average Signal Spectrum

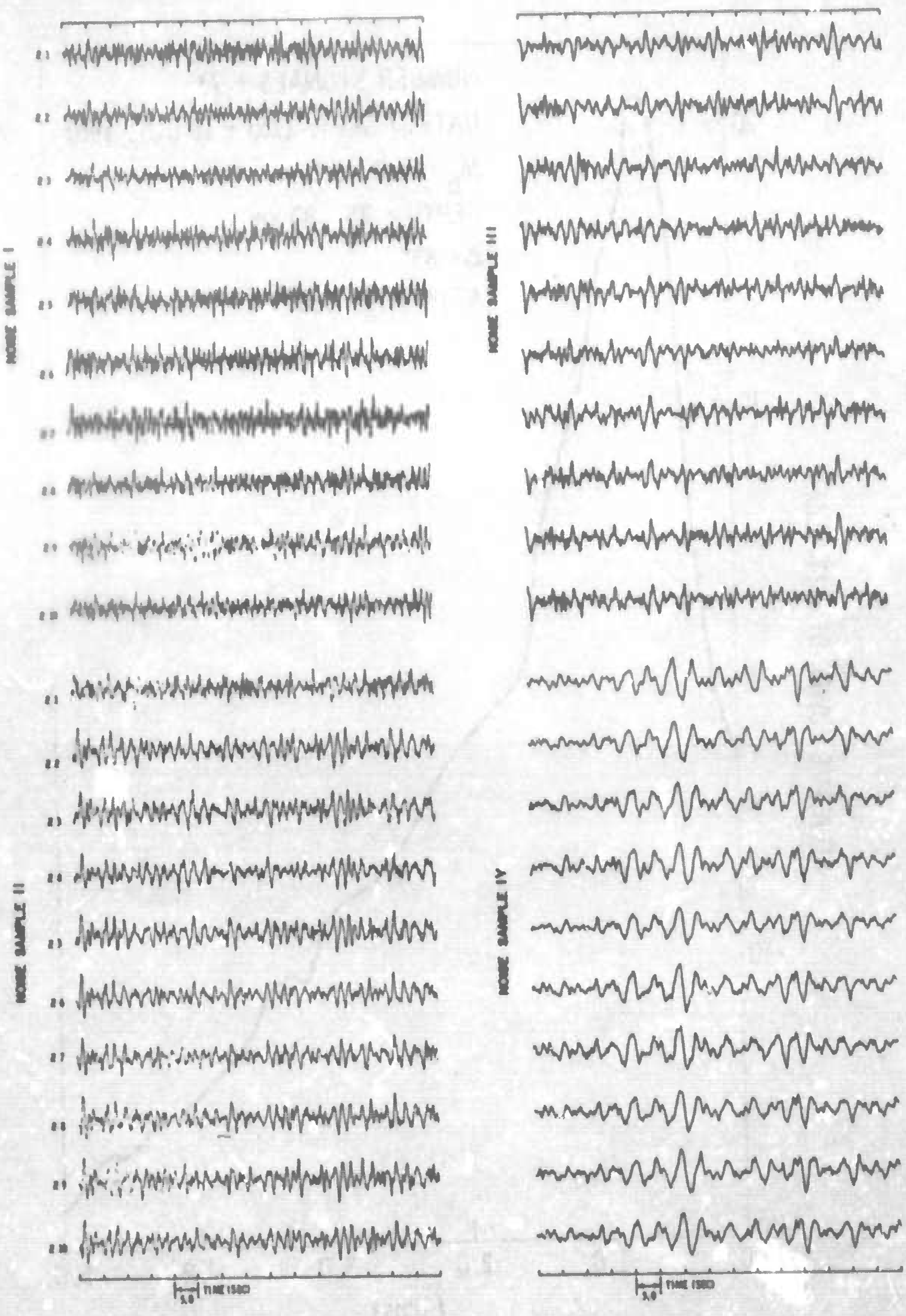

Figure V-7. Noise Samples I, II, III, and IV from 1965 CPO Noise Library

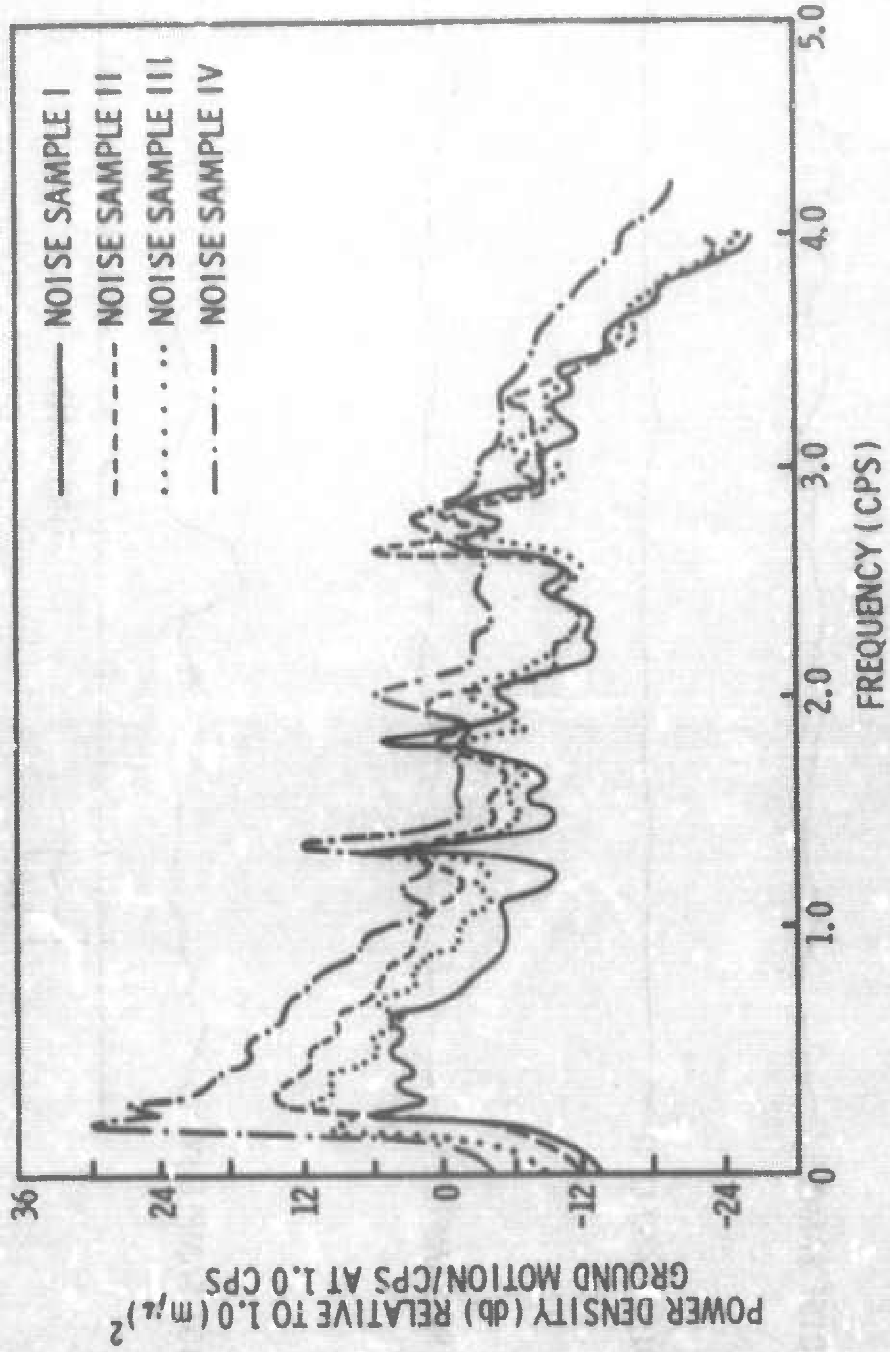

Figure V-8. Power Density Spectra of Z-10 for 1965 CPO Noise Samples I, II, III, and IV

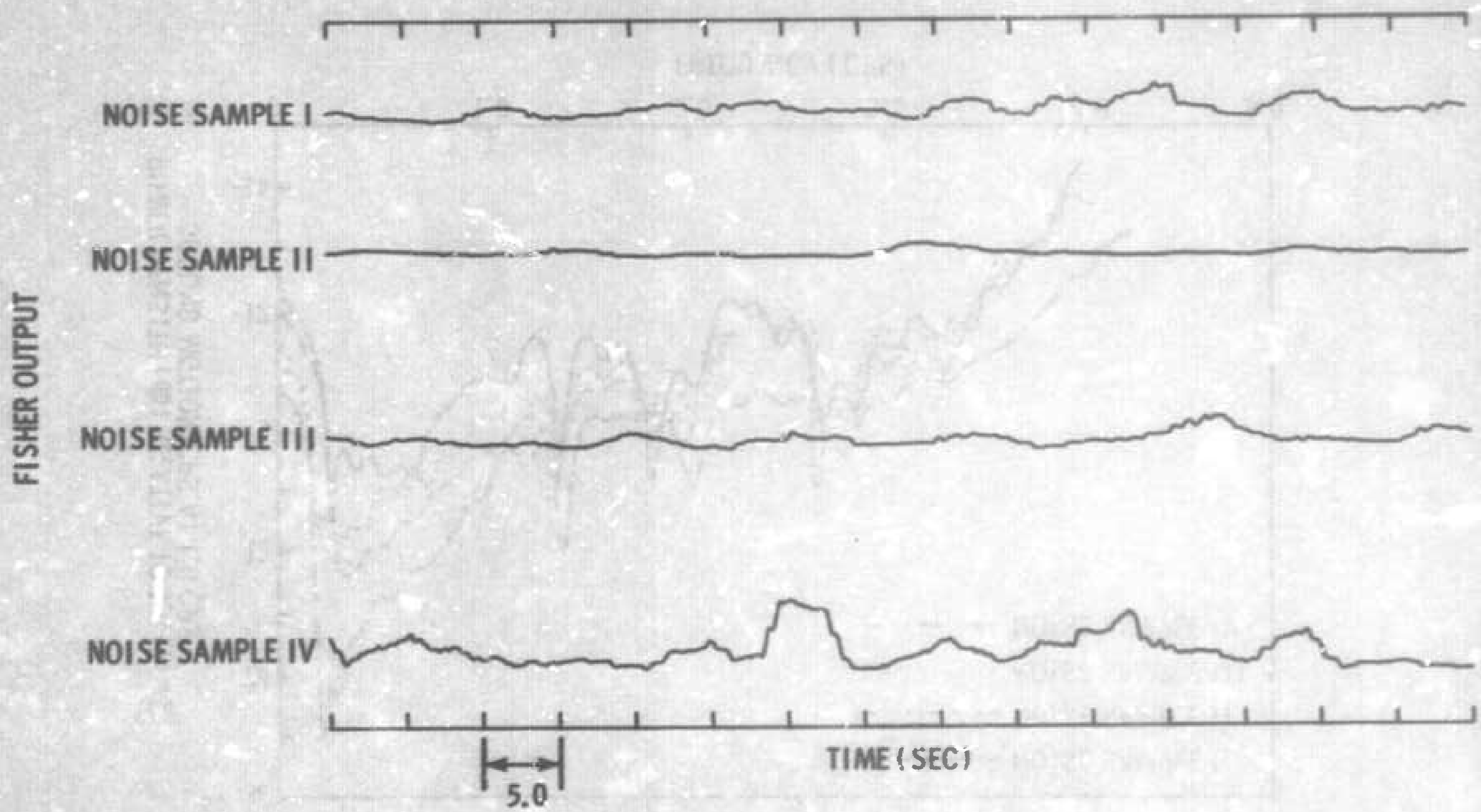

Figure V-9. Fisher Statistic for Noise Samples I, II, III, and IV

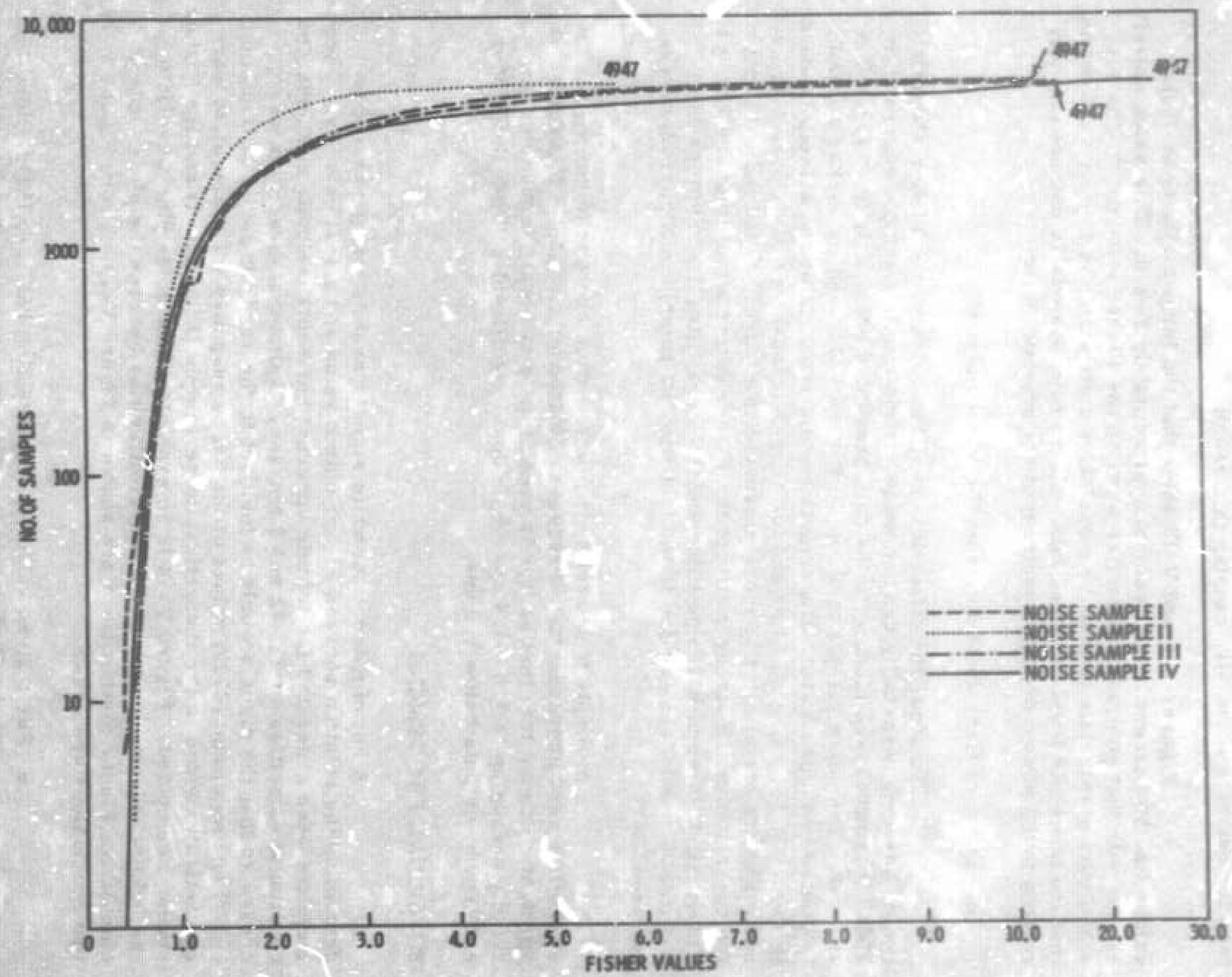

Figure V-10. Cumulative Distribution for Fisher Statistics for Noise Samples I, II, III, and IV

than for Samples II and III, causing this result.

Figures V-9 and V-10 show that the large majority of Fisher values (the 50-percent level) occur at approximately F=2.0. This value closely agrees with that published in earlier work on the Fisher statistic.[3] The real significant of this data is that the cumulative distribution in Figure V-10 shows that the threshold level for fixed false-alarm rate is variable and not strongly related to the power-density spectrum of the ambient noise.

2. Effect of Correlated Noise on the Fisher Statistic

To study the effect of correlated noise on the Fisher statistic (which assumes a spatially random noise distribution), a sample recorded in 1963[9] was processed along with the data presented previously in Figures V-4 and V-5. The noise sample is shown in Figure V-11, and its Fisher statistic is plotted in Figure V-12. The cumulative distribution for the sample is shown in Figure V-13, using no filter and for corner frequencies of 0.75, 1.0 and 1.25 cps. Results are similar to those presented in Figure V-5 and indicate that the correlated noise strongly effects the Fisher output statistic below 1.0 cps. The small difference in the no filter and 0.75 cps filter distributions in Figures V-5 and V-13 are due to the fact that the sample in Figure V-11 was not prewhitened.

Attempts to correlate the distribution changes to noise predictability were unsuccessful. Present estimates of the mantle P-wave noise spectrum indicate that this energy is predominate at lower frequencies and rapidly decays up to 1.0 - 1.4 cps which could significantly affect the Fisher and Wiener outputs below 1.0 cps.

E. SIGNAL PROCESSING

A set of theoretical white signal wavelets was generated to determine the relation between Fisher output value and signal velocity. These wavelets were generated for infinite apparent horizontal velocity and apparent horizontal velocities of 25, 12 and 8 km/sec. Azimuthal directions were chosen so that the signals would be incident to the array at points of maximum (180°) and minimum (270°) values of the array response. The wavelets were synthetically added to the theoretical noise sample (Figure V-1) and the Fisher statistic computed. Figure V-14 is an example of the noise plus wavelet for the infinite velocity case. Due to the similarities between the plots, only the cumulative Fisher distributions are shown in Figure V-15. From Figure V-15, two conclusions are drawn.

- For a given velocity, the direction has very little effect on the Fisher values. This result is expected due to the near symmetry of the CPO array.

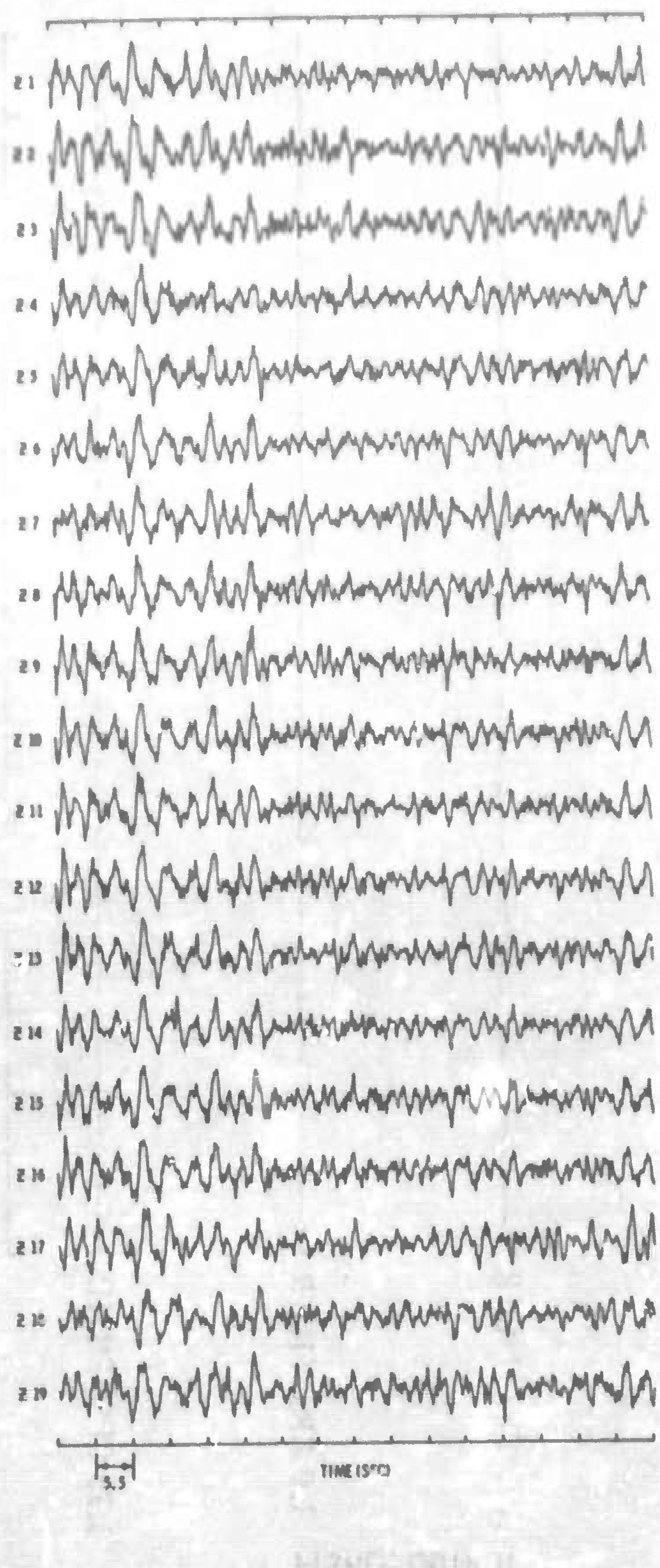

Figure V-11. CPO 1963 19-Channel Noise Sample

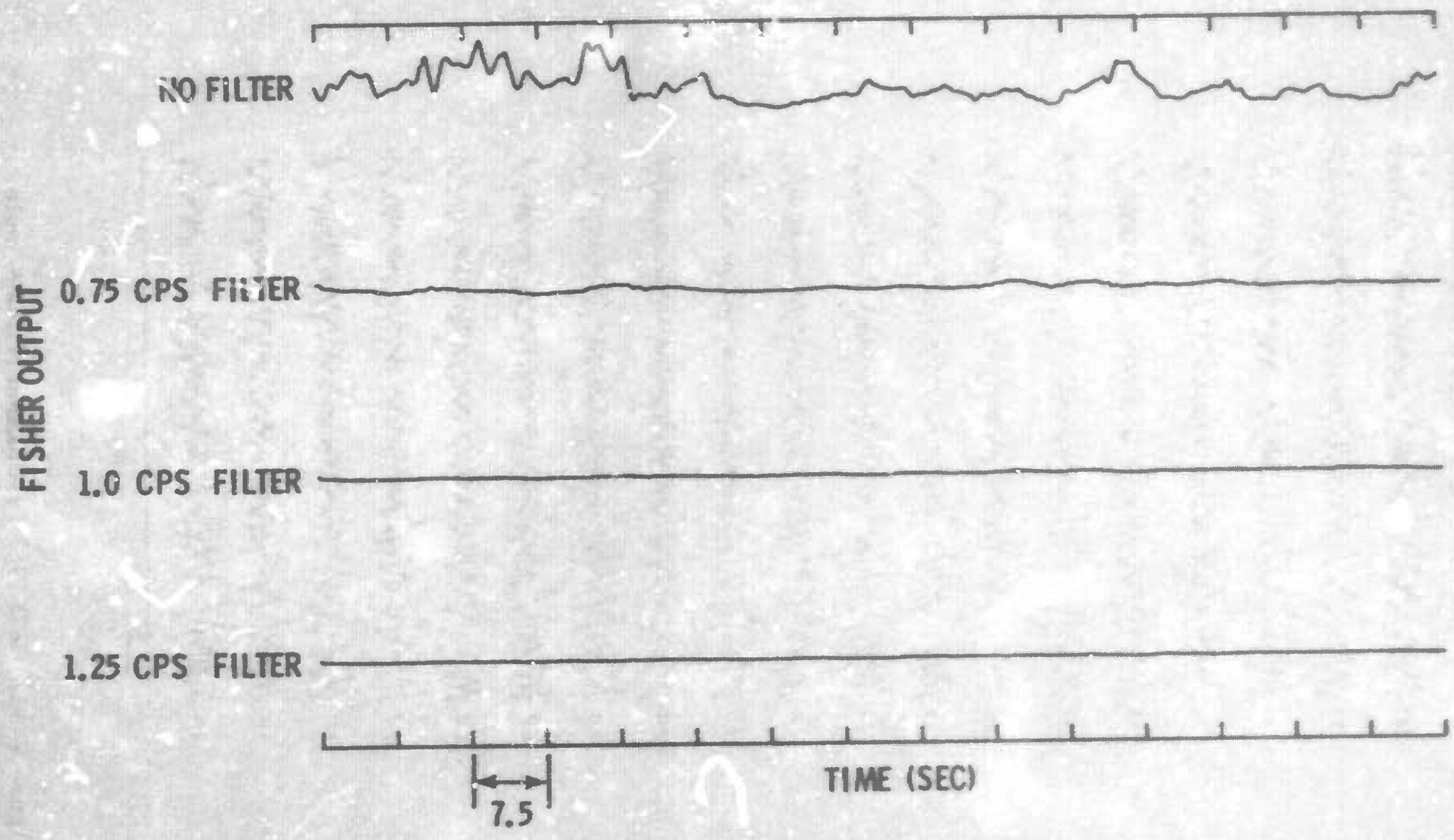

Figure V-12. Fisher Statistic for CPO 1963 19-Channel Noise Sample

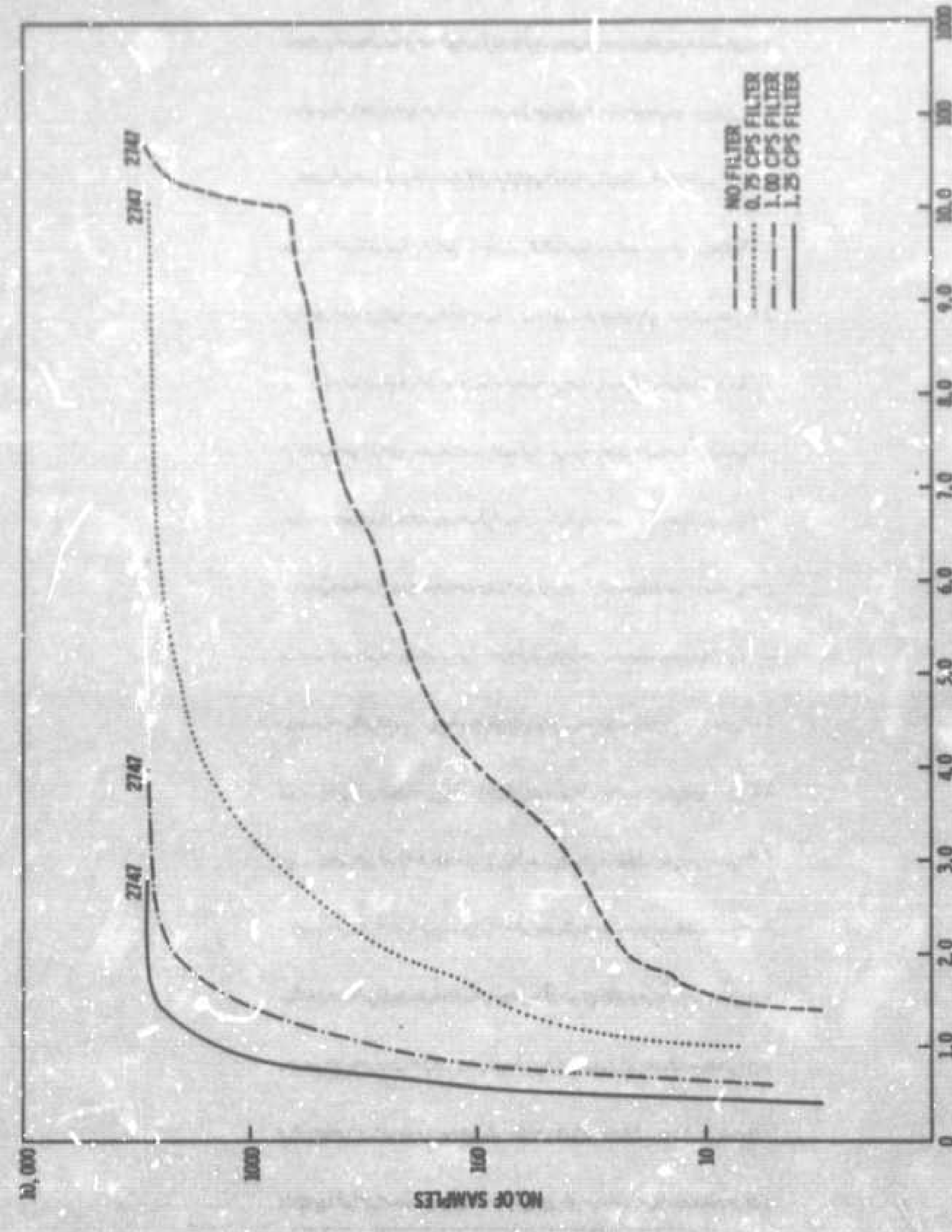

Figure V-13. Cumulative Distribution for Fisher Statistic for CPO 1963 19-Channel Noise Sample

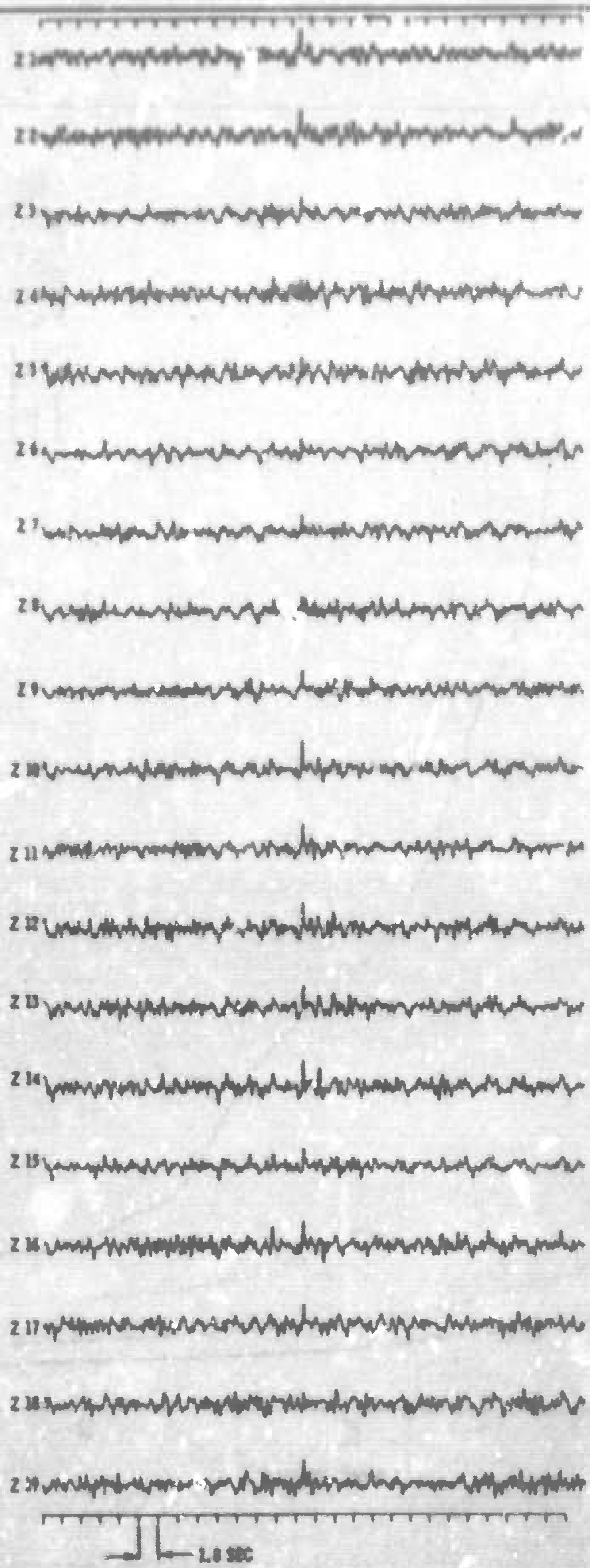

Figure V-14. CPO Theoretical Noise Sample Plus Wavelet for the Infinite Velocity Case

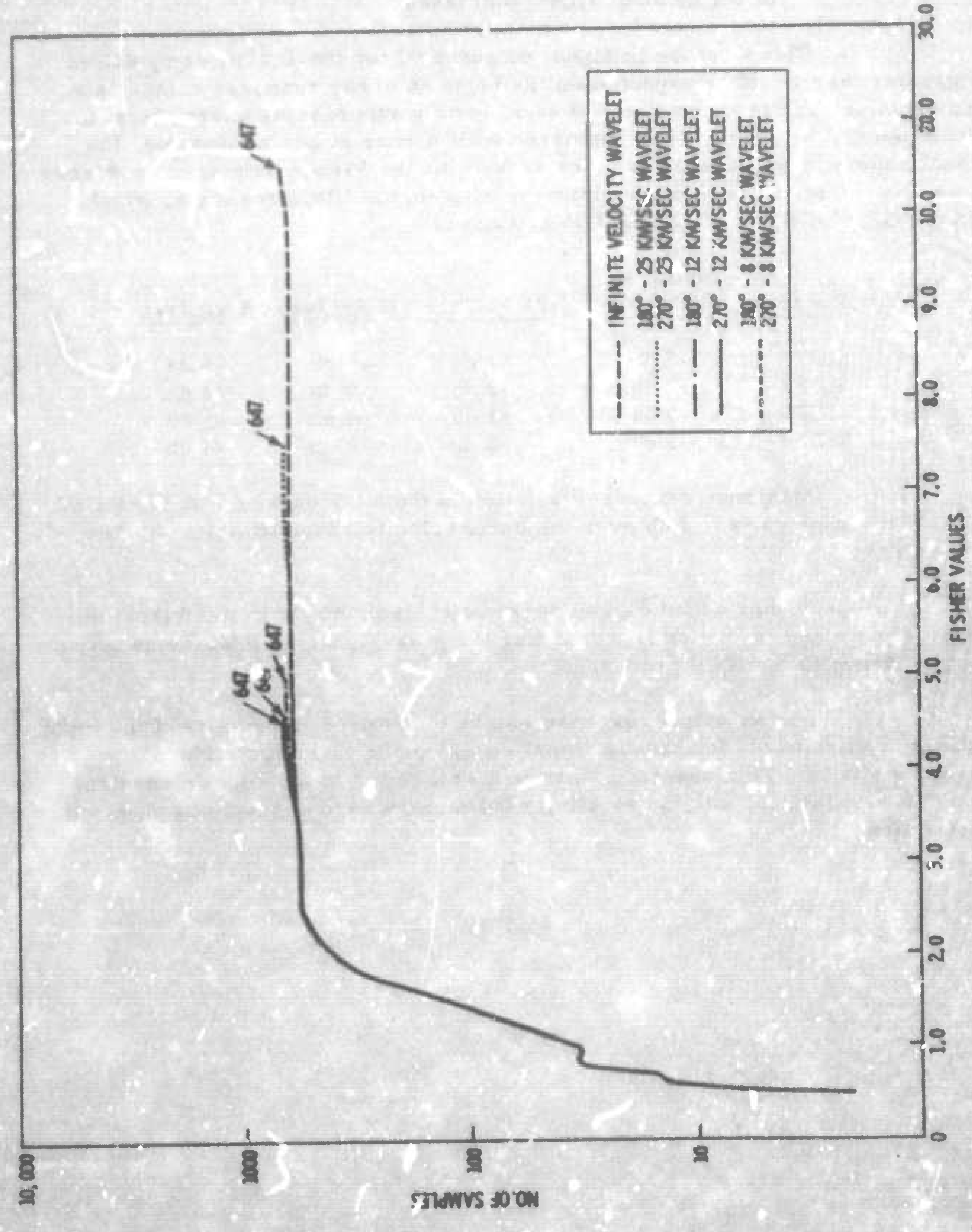

Figure V-15. Cumulative Distribution for Fisher Statistic for Theoretical Signal Wavelets

- The size of the Fisher values rapidly increase as the velocity of the incident signal increases.

The decrease in signal output level for the Fisher computation is greater than would be expected on the basis an array response comparison, and explains the Fisher property of significantly suppressing quarry blast information (Section III). When compared with Wiener pwoer processing, the signal suppression property is more severe for the Fisher output. The Wiener power output response is easily determined from the filter response, which for the CPO MCF's in Table III-1 at 1.0 cps is

Filter	Infinite Velocity	25 km/sec	12 km/sec	8 km/sec
MCF1	-0 db	-1 db	-4 db	-5 db
MCF2	+3 db	+2 db	-0 db	-4 db
MCF3	-0 db	-1 db	-4 db	-5 db
MCF4	-3 db	-3 db	-3 db	-4 db

Maximum response variation in the MCF data is 7 db for MCF2, while the Fisher varies 12 db over the same velocity range (infinite velocity to 8 km/sec).

Fisher output signal degradation is partially implied from the observation made in Section III regarding the peak-signal-to-RMS-noise output comparison with the MCF processes.

Fisher output response can be maximized in practice if the input data is beam-steered to enhance signal energy prior to computation of the Fisher statistic. This approach, although well suited to off-line processing, would be impractical with the existing hardware because of the fixed program restriction.

SECTION VI

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3. Seismic Data Laboratory, 1965: Analysis of Variance as a Method of Seismic Signal Detection, Rpt. 116, Contract AF 33(657)-12447, 25 Feb.

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6. Texas Instruments Incorporated, 1967: Auxiliary Processor Simulator, Cumberland Plateau Observatory Spec. Rpt. 3, Contract AF 33(657) -14648, 9 May.

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9. Texas Instruments Incorporated, 1965: Array Research Semiannual Tech. Rpt. 4, Contract AF 33(657)-12747, 15 Dec.

10. Texas Instruments Incorporated, 1966: Cumberland Plateau Seismological Observatory Annual Rpt. 1, Contract AF 33(657)-14648, 15 Sept.

APPENDIX

ADAPTIVE THRESHOLD DETECTION

science services division

APPENDIX

ADAPTIVE THRESHOLD DETECTION

At present, use of the existing MCF Auxiliary Processor system for automatic detection is limited due to non-time stationary Fisher and Wiener power output noise distributions. This limitation could be overcome by incorporating adaptive threshold detection into the Auxiliary Processor.

An adaptive threshold detector is one which automatically adjusts the detection threshold levels based upon the output noise history as defined over some specified period. Associated with the automatic detection capability must be a specified false-alarm rate and a learning rate.

Since a modification to the existing hardware is recommended, the storage requirements for the adaptive algorithm should be minimized, and the modifications should be incorporated into the present Auxiliary Processor drawer space.

A. RECOMMENDED SOLUTION

In order to meet the assumed hardware restrictions while still providing an adequate technical solution, it is recommended that the threshold level be determined from output history data which has been smoothed by an exponential time window. Mathematically, the output Fisher or Wiener power level would be described by a function $\bar{X}^{j}_{i+1}$ given by:

$$\bar{X}^{j}_{i+1} = \sum_{n=0}^{\infty} X^{j}_{i-n+1} \, e^{-n\alpha}$$

where:

i = time

j = output channel (one for Fisher and four for the Wiener power)

X^{j}_{i-n+1} = Output value of the jth channel at time $i-n+1$

This system provides for control of the learning speed with the time constant α, and includes all past history data to determine the output characteristic $\bar{X}^{j}_{i+1}$. The threshold would then be given by some value

$$T^{j}_{i+1} = K \cdot \bar{X}^{j}_{i+1}$$

where K is a constant which sets the desired false-alarm rate.

The exponential smoothing technique provides for weighting of the output statistic $\bar{X}^{j}_{i+1}$ as a function of time, i.e., the most recent data is weighted heaviest.

B. IMPLEMENTATION

The above equation can be simplified for on-time application as follows:

$$\bar{X}^{j}_{i+1} = \sum_{n=0}^{\infty} X^{j}_{i-n+1} \; e^{-n\alpha}$$

$$= X^{j}_{i+1} + \sum_{n=1}^{\infty} X_{i-n+1} \; e^{-n\alpha}$$

letting

$$n = n' + 1$$

$$\bar{X}^{j}_{i+1} = X^{j}_{i+1} + \sum_{n'=0}^{\infty} X_{i-n'} \; e^{-(n'+1)\alpha}$$

$$= X^{j}_{i+1} + e^{-\alpha} \sum_{n'=0}^{\infty} X^{j}_{i-n'} \; e^{-n\alpha}$$

However, $\bar{X}^{j}_{i} = \sum_{n'=0}^{\infty} X^{j}_{i-n'} \; e^{-n'\alpha}$

Therefore, $\bar{X}^{j}_{i+1} = X^{j}_{i+1} + \bar{X}^{j}_{i} \; e^{-\alpha}$

and the updated threshold is given by

$$T^j_{i+1} = K \bar{X}^j_{i+1} = K \left[X^j_{i+1} + \bar{X}^j_i \quad e^{-C} \right]$$

The threshold computation for the one output is thus reduced to two multiples and one add operation and storage requirements are reduced to a single word, $\bar{X}^j_i$.

A preliminary investigation of the hardware requirements for implementing this adaptive threshold algorithm indicates that existing hardware can be modified to include this capability with no increased core storage or drawer space requirements.

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13. ABSTRACT

Under Contract AF 33(657)-14648, both routine operation of the Cumberland Plateau Seismological Observatory and considerable applied research were conducted. During the last project year, on-line real-time detection and identification processing using the CPO Auxiliary Processor was implemented and evaluated at CPO for the purpose of studying automatic detection processing. The CPO Auxiliary Processor computes two classes of detection outputs, the Fisher analysis of variance statistic and the Wiener power statistic, and one class of identification output, the United Kingdom technique. These detection outputs were compared on line against a fixed signal threshold level, providing a continuous real-time "yes-no" output for signal. However, the fixed-threshold detection levels were initially difficult to determine accurately and, once determined, it was found that they were highly non-time stationary. Adaptive threshold detectors incorporated into the Auxiliary Processor could overcome the non-time stationarity of the threshold detectors. Off-line applied research was performed to support the on-line research.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cumberland Plateau Observatory						
CPO Auxiliary Processor						
On-Line Real-Time Detection and Identification						
Automatic Detection Processing						
Fisher Analysis-of-Variance Statistic						
Wiener Power Statistic						
United Kingdom Technique						
Fixed Signal Threshold Level						
Adaptive Threshold Detectors						

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